

FOURTH EDITION

FRED HALL & ROGER GREENO

BUILDING SERVICES HANDBOOK

INCORPORATING CURRENT BUILDING & CONSTRUCTION REGULATIONS



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BUILDING SERVICES HANDBOOK

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BUILDING SERVICES HANDBOOK

Fourth edition

Fred Hall

and

Roger Greeno



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PREFACE TO FOURTH EDITION

This new and updated edition continues the successful combination of consolidated text, generous use of illustrations and simplified design calculations and graphics.

Since the previous edition, the impact of new energy conservation measures has materialised in revised installation procedures and practice standards. It has been a time to absorb these requirements and consider the changed role that building services engineering now has on the design and construction of our buildings. In less than three decades, the mechanical and electrical (M&E) engineer's title and job function as specifier of pipes, ducts and cables has changed to that of architectural design team consultant and construction site management co-ordinator. Input to these areas is critical to the success of a building and it includes a vast range of facilities and provisions, not least those contained herein. What would Louis Kahn (see Preface to First edition) make of it all now?

This book is presented in a comprehensive format to emphasise the importance of the numerous specialist professions and trades. It combines with the companion volume *Building Construction Handbook* to introduce the principles of the modern serviced building, with regard to the impact the subject has on contemporary design. This book is not intended as prescriptive, neither is it extensive. It is by definition a handbook, and as such is intended to provide the reader with an understanding of a wide range of topics. Where appropriate, sources for further reading and research are provided.

Roger Greeno, 2007

PREFACE TO THIRD EDITION

Since publication of the second edition, revised Building Regulations have introduced new measures to improve energy conservation and to reduce environmental contamination, global warming and climatic change. This new edition considers the means for satisfying current objectives to reduce the amount of CO_2 emissions that pollute the atmosphere from fuel-burning appliances. Domestic plumbing, hot water and heating installations are specifically targeted. These systems produce about one quarter of the UK's carbon emissions and also draw significantly on finite fossil fuel resources. This enlarged edition incorporates practical measures for efficient use of fuel-burning plant and effective use of system controls.

Where necessary, existing topics are updated and developed to represent new technologies and procedures. Guidance on regulation changes provides for awareness for the needs of the disabled in the layout, design and use of sanitary facilities, transport within buildings and accessibility of controls.

The established page format of simple illustrations, defined text and design calculations where appropriate are retained as a comprehensive presentation of subject matter. Legislative references and practice standards are provided for further reading.

Roger Greeno, Guildford, 2005

PREFACE TO SECOND EDITION

The success of the first edition as a reader for building and services further and higher education courses, and as a general practice reference, has permitted further research and updating of material in this new publication.

This new edition retains the existing pages as established reference, updates as necessary and develops additional material in response to evolving technology with regard to the introduction of new British Standards, European Standards, Building Regulations, Water Regulations and good practice guidance. Where appropriate, references are provided to these documents for further specific reading.

Roger Greeno, Guildford, 2003

PREFACE TO FIRST EDITION

The capital and installation costs of building services in modern buildings can take up 50% of the total construction budget. For highly serviced buildings such as sports centres, this figure can easily exceed 75%. Services can also take up 15% of a building's volume. Therefore building services cannot be ignored. Architects have learnt to accept and accommodate the increased need for pipes, ducts and cabling encroaching on to their designs. Some with reluctance, not least Louis Kahn when writing in *World Architecture* in 1964: 'I do not like ducts, I do not like pipes. I hate them so thoroughly, I feel that they have to be given their place. If I just hated them and took no care, I think they would invade the building and completely destroy it.' Not all architects have chosen to compete with the ducting and mechanical plant. Some have followed the examples of Renzo Piano and Richard Rogers by integrating it with the construction and making it a feature of the building, viz. the Pompidou Centre in Paris and the Lloyds Building in London.

Building services are the dynamics in a static structure, providing movement, communications, facilities and comfort. As they are unavoidable, it is imperative that architects, surveyors, builders, structural engineers, planners, estate managers and all those concerned with the construction of buildings have a knowledge and appreciation of the subject.

This book incorporates a wide range of building services. It provides a convenient reference for all construction industry personnel. It is an essential reference for the craftsman, technician, construction site manager, facilities manager and building designer. For students of building crafts, national certificates and diplomas, undergraduates and professional examinations, this book will substantiate study notes and be an important supplement to lectures.

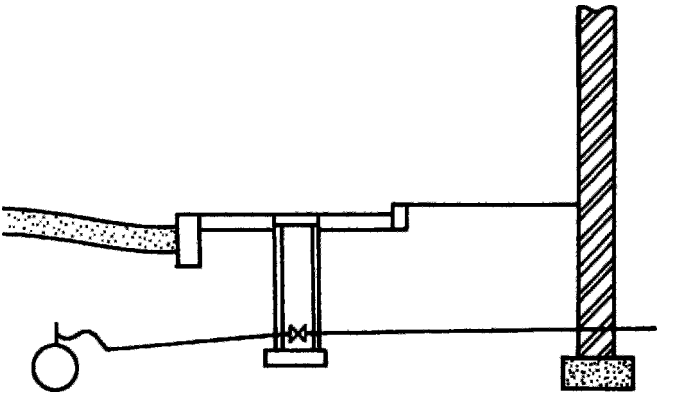
The services included in this book are cold and hot water supplies, heating, ventilation, air conditioning, drainage, sanitation, refuse and sewage disposal, gas, electricity, oil installation, fire services, transportation, accommodation for services, energy recovery and alternative energy. The emphasis throughout is economic use of text with a high proportion of illustrations to show the principles of installation in a comprehensive manner. Where appropriate, subjects are supplemented with references for further reading into legislative and national standards. Most topics have design applications with charts and formulae to calculate plant and equipment ratings or sizes.

This book has been developed from the second edition of *Essential Building Services and Equipment* by Frederick E. Hall. Fred endorsed this with thanks to his '. . . late wife for her patience and understanding during the preparation of the first edition.' I would like to add my sincere thanks to my former colleague, Fred, for allowing me to use his material as the basis for this new presentation. It is intended as a complementary volume to the *Building Construction Handbook* by Roy Chudley and Roger Greeno, also published by Butterworth-Heinemann.

Roger Greeno, Guildford, 2000

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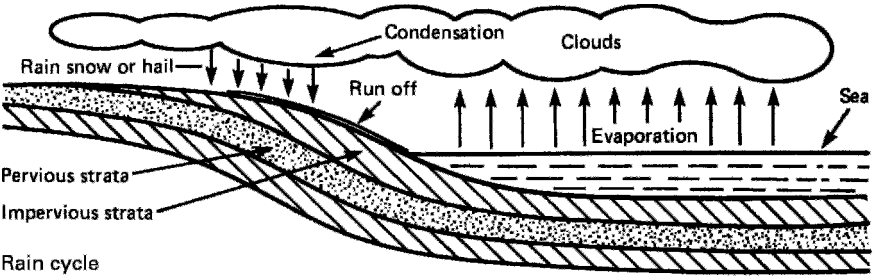
1 COLD WATER AND SUPPLY SYSTEMS



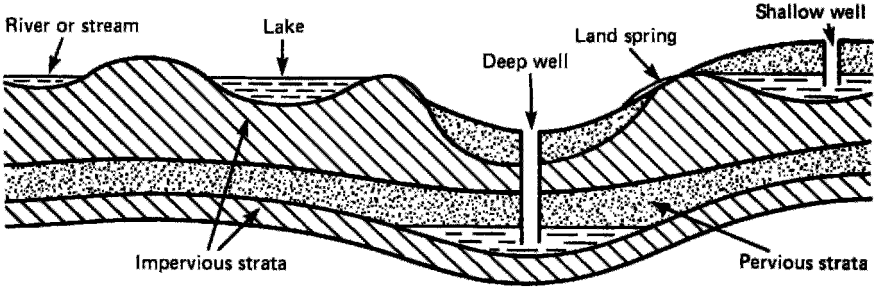
RAIN CYCLE – SOURCES OF WATER SUPPLY
ACIDITY AND ALKALINITY IN WATER
FILTRATION OF WATER
STERILISATION AND SOFTENING
STORAGE AND DISTRIBUTION OF WATER
VALVES AND TAPS
JOINTS ON WATER PIPES
PIPE JOINTING MATERIALS
WATER MAINS
DIRECT SYSTEM OF COLD WATER SUPPLY
INDIRECT SYSTEM OF COLD WATER SUPPLY
BACKFLOW PROTECTION
SECONDARY BACKFLOW PROTECTION
COLD WATER STORAGE CISTERNS
COLD WATER STORAGE CALCULATIONS
BOOSTED COLD WATER SYSTEMS
DELAYED ACTION FLOAT VALVE
PIPE SIZING BY FORMULA
PIPE SIZES AND RESISTANCES
HYDRAULICS AND FLUID FLOW

Surface sources – Lakes, streams, rivers, reservoirs, run off from roofs and paved areas.

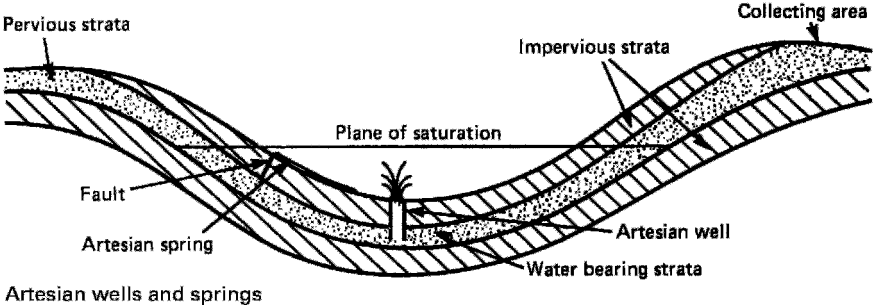
Underground sources – Shallow wells, deep wells, artesian wells, artesian springs, land springs.



Rain cycle



Surface and normal underground supplies



Artesian wells and springs

Acid – a substance containing hydrogen which can be replaced by other elements. Litmus paper in the presence of acidic water turns red.

Alkali – a substance which will neutralise acid by accepting its hydrogen ions (H^+). Litmus paper in the presence of alkaline water turns blue.

More accurate definitions can be obtained by using hydrochemical electric metres. These measure the amount of hydrogen ions (H^+) in a relative proportion of water. This measure of acidity or alkalinity in solution is referred to numerically from 0–14 as the pH value.

- pH < 7 indicates acidity
- pH > 7 indicates alkalinity
- pH = 7 chemically pure

The quality of processed water is unlikely to be pure due to contamination at source.

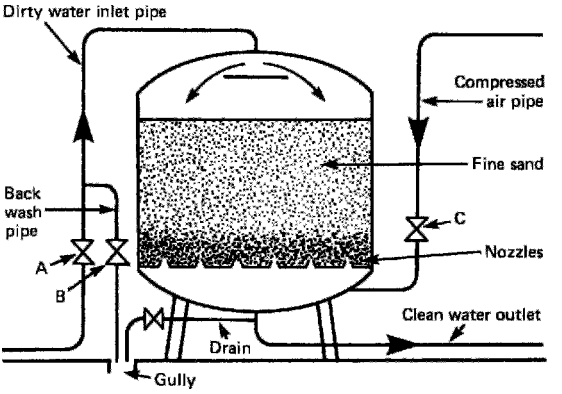
Rainwater – contaminated by suspended impurities as it falls through the air. These impurities are principally carbon dioxide, sulphur and nitrous oxides originating from domestic flue gases and industrial manufacturing processes. The mixture of these impurities and rainfall produce 'acid rain', an occurrence frequently blamed for the destruction of plant life.

Surface and substrata water sources – contaminated by dissolved inorganic materials such as calcium, magnesium and sodium. These are responsible for water hardness as described on pages 5 and 17. Organic matter from decaying vegetation, animals and untreated waste water can also contaminate ground water supplies. These are normally associated with ammonia compounds in the water or bacteria. Certain types of bacteria present in water can be responsible for outbreaks of typhoid, cholera and dysentery. Chlorination, as described on page 5 is applied to filtered water to destroy any remaining bacterial microbes before general distribution through service reservoirs and mains.

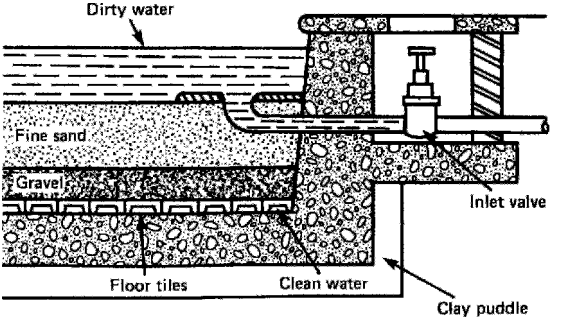
The following table shows the quantity of pollutant microbes present during the stages of water processing, as described on pages 4–6:

Source/process	Typical pollutant microbe count per litre
River	41000
Impounding reservoir	1500
Primary filter	500
Secondary filter	50
Chlorination	0
Service reservoir	0
Distribution main	0

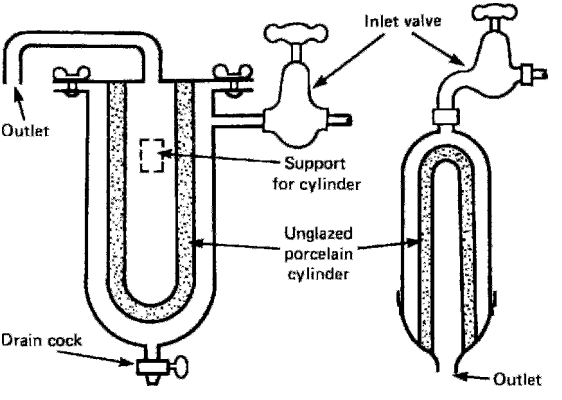
Pressure filter – rate of filtration 4 to 12 m^3 per m^2 per hour. To backwash, valve A is closed and valves B and C opened. Compressed air clears the sand of dirt. Diameter = 2·4 m.



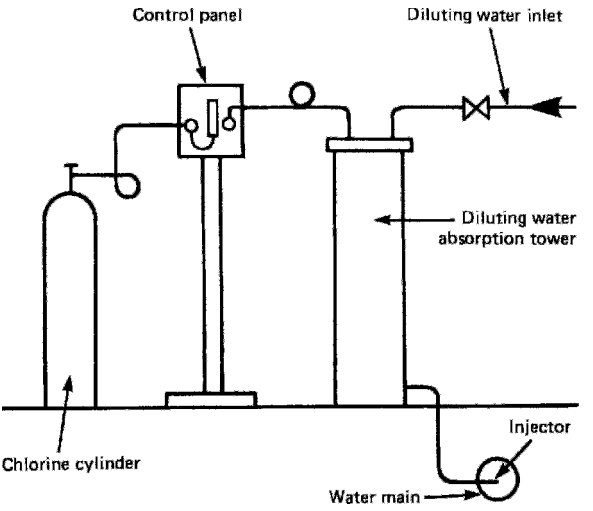
Slow sand filter bed – rate of filtration 0·2 to 1·15 m^3 per m^2 per hour. Filter beds can occupy large areas and the top layer of sand will require removal and cleaning at periodic intervals.



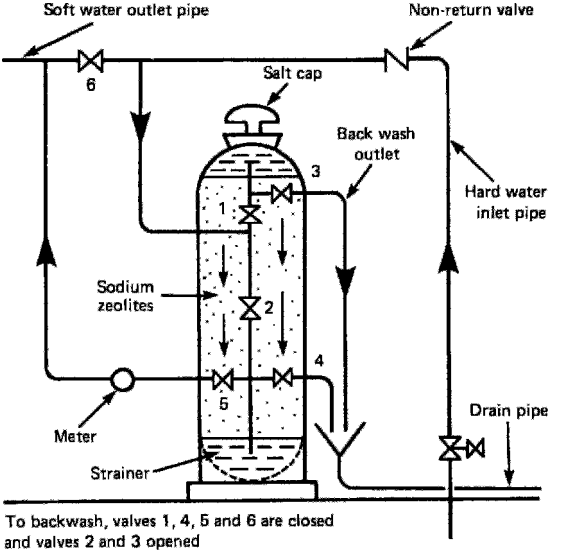
Small domestic filter – the unglazed porcelain cylinder will arrest very fine particles of dirt and even micro-organisms. The cylinder can be removed and sterilised in boiling water for 10 minutes.



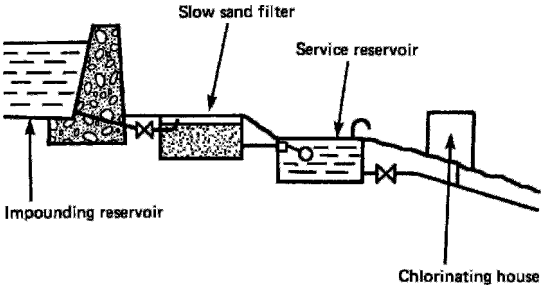
Sterilisation by chlorine injection – water used for drinking must be sterilised. Chlorine is generally used for this purpose to destroy organic matter. Minute quantities (0·1 to 0·3 p.p.m.) are normally added after the filtration process.



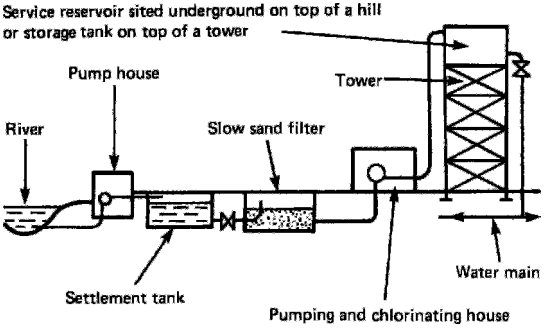
Softening of hard water by base exchange process – sodium zeolites exchange their sodium base for calcium (chalk) or magnesium bases in the water. Sodium zeolite plus calcium carbonate or sulphate becomes calcium zeolite plus sodium carbonate or sulphate. To regenerate, salt is added; calcium zeolite plus sodium chloride (salt) becomes sodium zeolite plus calcium chloride which is flushed away.



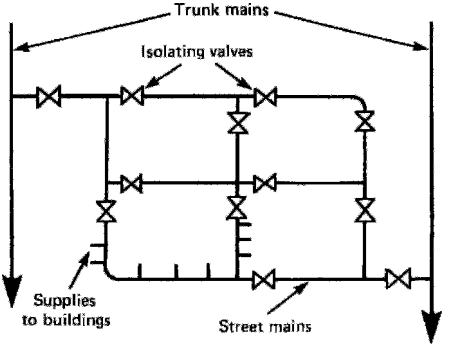
Gravitational distribution – the water from upland gathering grounds is impounded in a reservoir. From this point the water is filtered and chlorinated before serving an inhabited area at lower level. There are no pumping costs.



Pumped distribution – water extracted from a river is pumped into a settlement tank, subsequently filtered and chlorinated. Pump maintenance and running costs make this process more expensive than gravity systems.



Ring main distribution – water mains supplying a town or village may be in the form of a grid. This is preferable to radial distribution as sections can be isolated with minimal disruption to the remaining system and there is no more opportunity for water to maintain a flow.

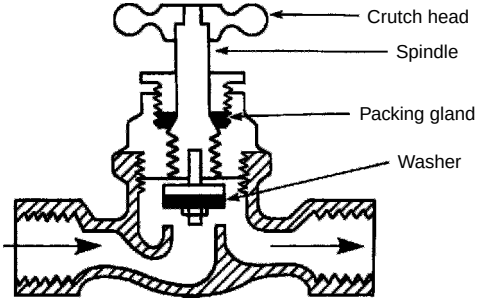


The globe-type stop valve is used to control the flow of water at high pressure. To close the flow of water the crutch head handle is rotated slowly in a clockwise direction gradually reducing the flow, thus preventing sudden impact and the possibility of vibration and water hammer.

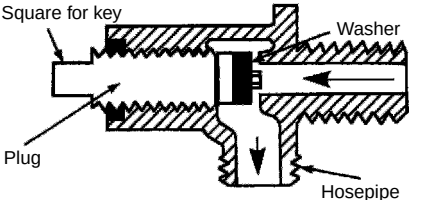
The gate or sluice valve is used to control the flow of water on low pressure installations. The wheel head is rotated clockwise to control the flow of water, but this valve will offer far less resistance to flow than a globe valve. With use the metallic gate will wear and on high pressure installations would vibrate.

The drain valve has several applications and is found at the lowest point in pipe systems, boilers and storage vessels.

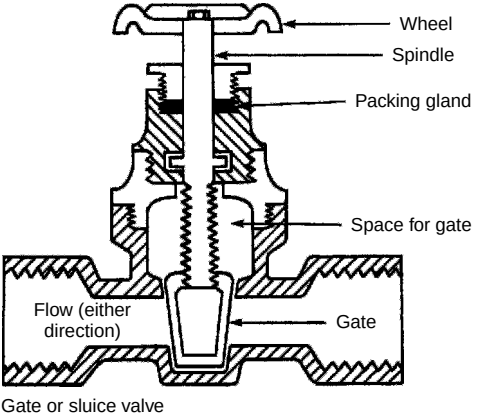
For temperatures up to 100°C valves are usually made from brass. For higher temperatures gun metal is used. Brass contains 50% zinc and 50% copper. Gun metal contains 85% copper, 5% zinc and 10% tin.



Stop valve (globe type)

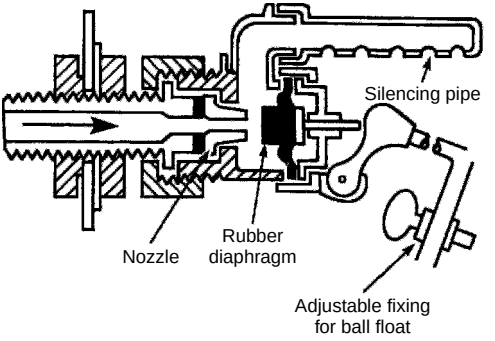


Drain valve

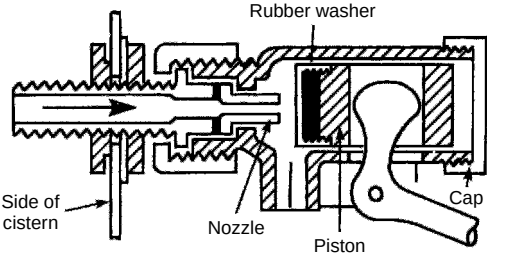


Gate or sluice valve

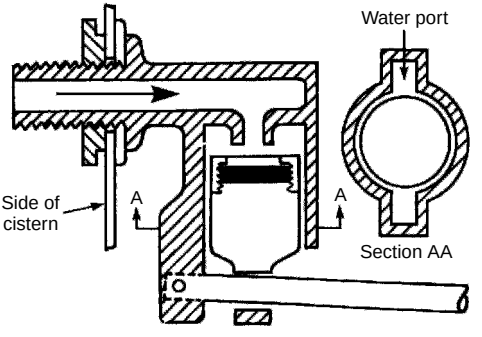
Float valves are automatic flow control devices fitted to cisterns to maintain an appropriate volume of water. Various types are in use. The diaphragm type is the least noisy as there is less friction between moving parts. The Portsmouth and Croydon-type valves have a piston moving horizontally or vertically respectively, although the latter is obsolete and only likely to be found in very old installations. Water outlets must be well above the highest water level (see page 19) to prevent back siphonage of cistern water into the main supply. Nozzle diameters reduce as the pressure increases. High, medium and low pressure valves must be capable of closing against pressures of 1380, 690 and 275 kPa respectively.



Diaphragm float valve BS 1212–2 and 3



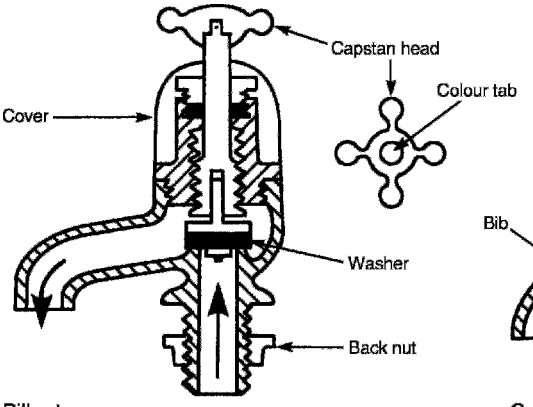
Portsmouth/piston float valve BS 1212–1



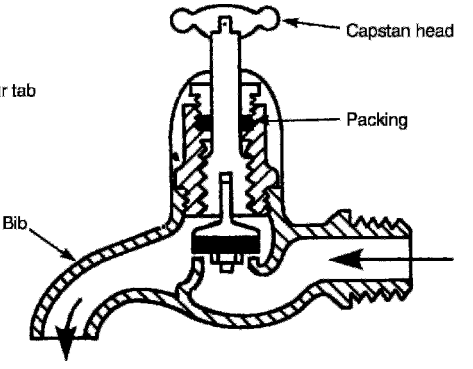
Croydon float valve

The pillar tap is used to supply water to basins, baths, bidets and sinks. Combined hot and cold pillar taps are available with fixed or swivel outlet. The outlet of these taps must be bi-flow, i.e. separate waterways for hot and cold water to prevent crossflow of water within the pipework.

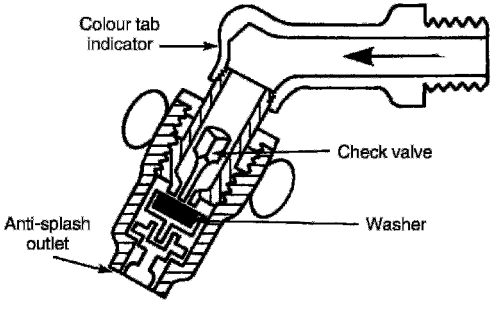
The bib tap is for wall fixing, normally about 150 mm above a sanitary appliance. The `Supatap' bib tap permits a change of washer without shutting off the water supply. It is also available in pillar format. Quarter-turn taps are easy to operate by hand or elbow, therefore are suitable for use by the disabled and medical practitioners.



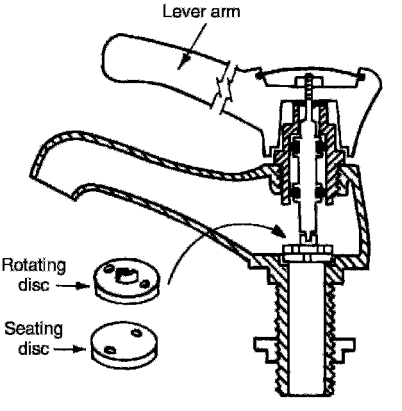
Pillar tap



Conventional bib tap



'Supatap' bib tap



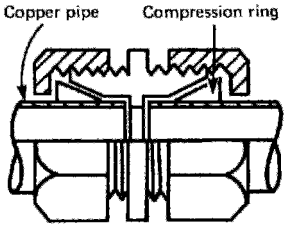
Quarter-turn ceramic disc pillar tap

Copper pipes may be jointed by bronze welding. Non-manipulative compression joints are used on pipework above ground and manipulative compression joints are used on underground pipework. The latter are specifically designed to prevent pipes pulling out of the joint. Push-fit joints are made from polybutylene. These provide simplicity of use and savings in time. Capillary joints have an integral ring of soft solder. After cleaning the pipe and fitting with wire wool and fluxing, heat application enables the solder to flow and form a joint. Solder alloy for drinking water supplies must be lead free, i.e. copper and tin.

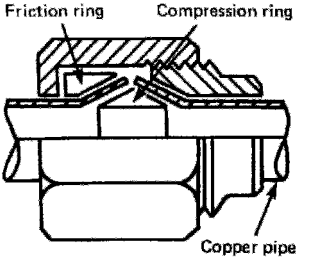
The Talbot joint is a push-fit joint for polythene pipes. A brass ferrule or support sleeve in the end of the pipe retains the pipe shape.

Threaded joints on steel pipes are sealed by non-toxic jointing paste and hemp or polytetrafluorethylene (PTFE) tape. A taper thread on the pipe will help to ensure a water-tight joint. Union joints permit slight deflection without leakage.

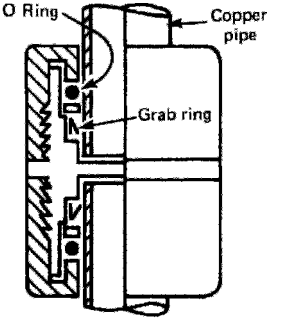
Lead pipes are no longer acceptable due to the risk of poisoning.



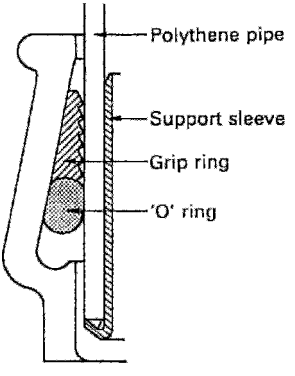
Non-manipulative compression joint on copper pipes



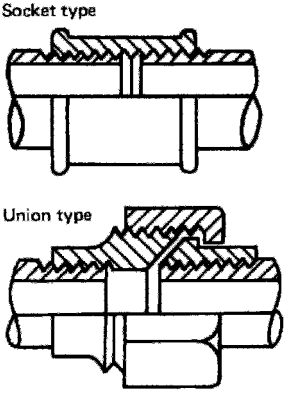
Manipulative compression joint on copper pipes



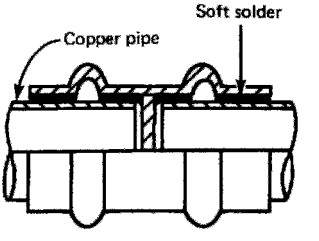
Acorn push-fit joint on copper pipes



The Talbot push-fit joint on polythene pipes



Screwed joints on mild steel pipes



When the fitting is heated solder flows

Soft soldered capillary joint on copper pipes

Linseed oil `white' jointing paste – a blend of linseed oil and clay which surface hardens to form a strong, dense joint. Used mainly on threaded steel pipework with fibrous hemp reinforcement between the threads. Microbial action can break down the linseed component and the hemp can degrade, therefore not recommended for use on drinking water supplies. Synthetic reinforcement fibres are more durable. Unreinforced paste is suitable for gas and steam pipe lines. Graphite is sometimes added to the paste for use on steam, as this eases joint breakage when undertaking maintenance and alterations. A manganese additive for use on steam pipes provides greater strength.

Silicone oil jointing paste – otherwise known as acetosilane. Combined with synthetic reinforcement fibres, this compound may be used on drinking water supplies. It is also suitable for jointing hot water and gas pipes. Non-setting, non-cracking and flexible, therefore easily broken for maintenance and alterations.

BS 6956-5: Jointing materials and components

Resin-based compounds – these are specified for chemical and oil pipe joints where the liquid conveyed may contain solvents which could weaken oil-based sealants. Resin and fillers are mixed with a catalyst and after application to pipe threads, tightened joints will require time to set.

PTFE tape – wound into threads prior to joint tightening. Chemical and temperature resistant with an element of flexibility. Suitable for water and gas pipe joints. Also available as a liquid, but relatively expensive.

BS 7786: Specification for unsintered PTFE tape

BS EN 751-3: Sealing materials for metallic threaded joints

Solders and fluxes – the established method for economically jointing copper pipe and fittings. Solder types:

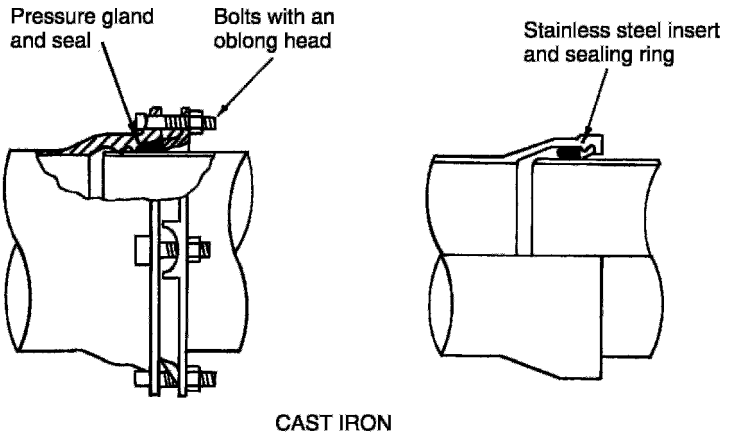
- 29% tin + 71% lead. Traditionally used for all joints but now prohibited on drinking water supplies because of the lead content. Melting point = 210°C.
- 63% tin + 37% lead. Bit solder for electronic applications. Melting point = 185°C.
- 99% tin + 1% copper. Lead-free for drinking water supplies. Melting point = 235°C.

BS 6920: Suitability of non-metallic products in contact with water.

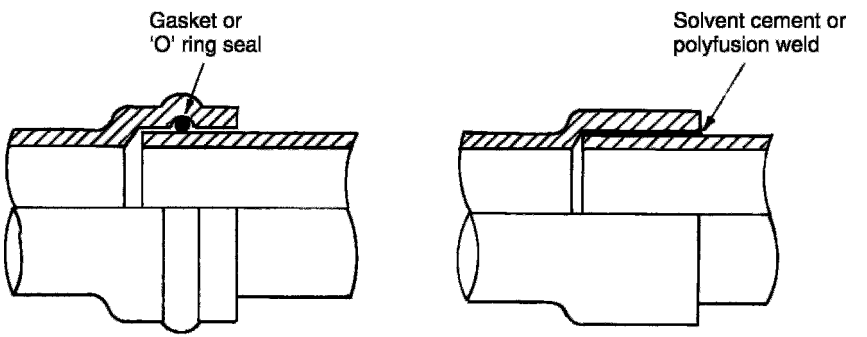
BS EN 29453: Soft solder alloys. Chemical compositions and forms.

Fluxes are classified as passive or self-cleaning. They are available in liquid or paste format and function by preventing cleaned surfaces tarnishing under heat. Passive fluxes do not contain any free acid and will require heat application to effect cleaning. These are generally known as water soluble organic fluxes and are the preferred choice by gas companies due to the flux's non-corrosive properties. Water-soluble fluxes are also preferred for use with lead-free solders and are easily cleaned from finished joints. Self-cleansing fluxes contain an acid, usually hydrochloric. This type of flux begins to clean tarnished copper as soon as applied. Heat application accelerates the process. Any flux residue must be cleaned from the pipe surface to prevent corrosion. Deposits internally are removed by flushing the system.

Water mains have been manufactured from a variety of materials. The material selected must be compatible with the water constituents, otherwise corrosion and decomposition of the pipes may occur. Contemporary materials which suit most waters are ductile cast iron to BS EN 545 and uPVC to BS EN 1452-2. The water undertaking or authority must be consulted prior to laying mains to determine suitable materials, laying techniques and pipe diameter. Firefighting and hydrant requirements will prioritise the criteria with a minimum pressure of 30 m head (300 kPa) from a 75 mm diameter pipe supplied from both ends, or 100 mm diameter from one end only. Bedding of mains is usually a surround of shingle to accommodate any movement. uPVC pipes are pigmented blue for easy identification in future excavations and cast iron has a blue plastic tape attached for the same reason.

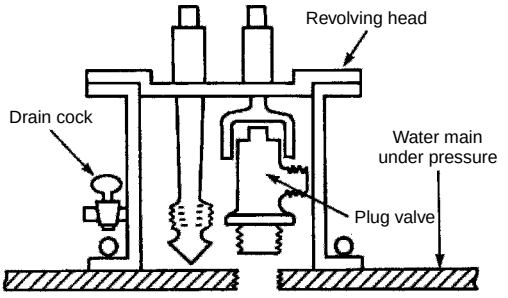


CAST IRON

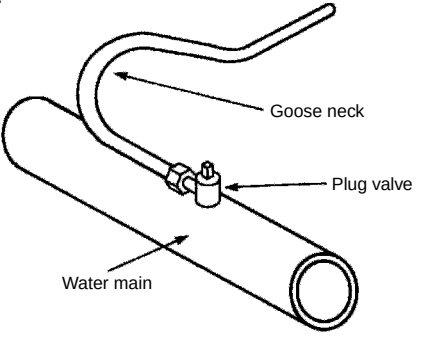


uPVC

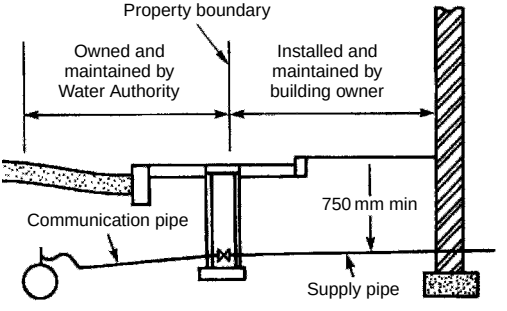
The water authority requires at least 7 days' written notice for connection to their supply main. The main is drilled and tapped live with special equipment, which leaves a plug valve ready for connection to the communication pipe. A goose neck or sweeping bend is formed at the connection to relieve stresses on the pipe and valve. At or close to the property boundary, a stop valve is located with an access compartment and cover at ground level. A meter may also be located at this point. The communication and supply pipe should be snaked to allow for settlement in the ground. During warm weather, plastic pipes in particular should be snaked to accommodate contraction after backfilling.



Tapping of water main

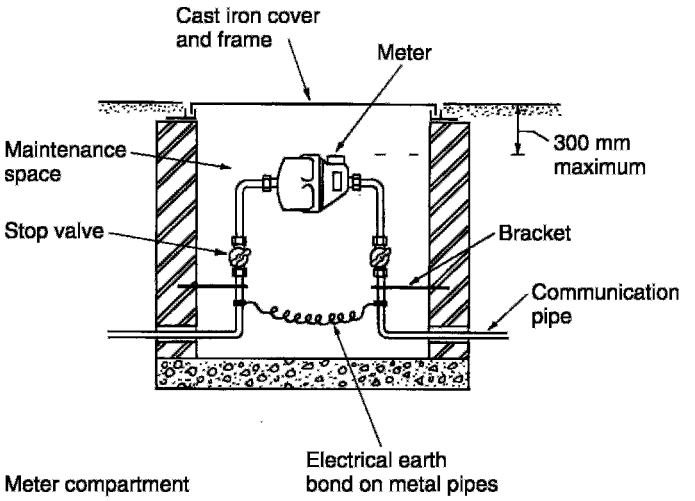


View of water main connection

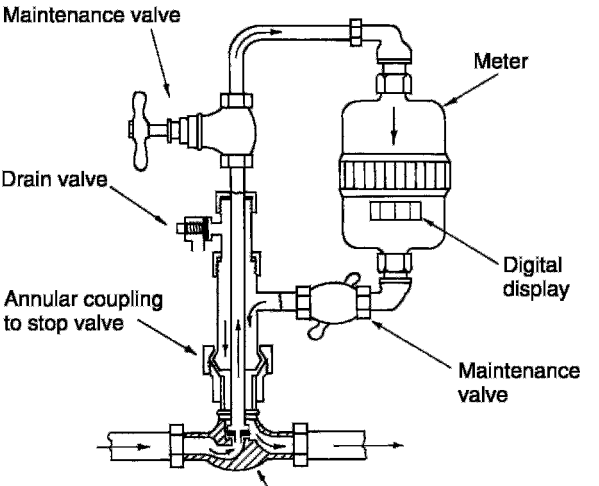


Detail of supply to building

Water meters are installed at the discretion of the local water authority. Most require meters on all new build and conversion properties, plus existing buildings which have been substantially altered. In time, in common with other utilities, all buildings will have metered water supply. Meters are either installed in the communication pipe, or by direct annular connection to the stopvalve. If underground location is impractical, the water authority may agree internal attachment to the rising main.



Meter compartment



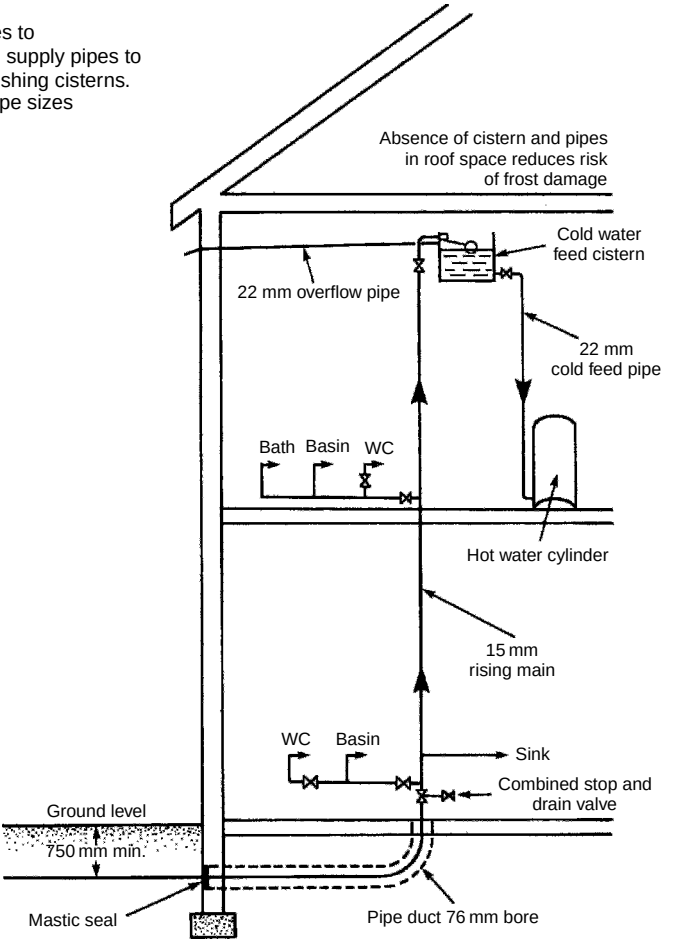
Patent meter connection

Existing stop valve

For efficient operation, a high pressure water supply is essential particularly at periods of peak demand. Pipework is minimal and the storage cistern supplying the hot water cylinder need only have 115 litres capacity. The cistern may be located within the airing cupboard or be combined with the hot water cylinder. Drinking water is available at every draw-off point and maintenance valves should be fitted to isolate each section of pipework. With every outlet supplied from the main, the possibility of back siphonage must be considered.

Back siphonage can occur when there is a high demand on the main. Negative pressure can then draw water back into the main from a submerged inlet, e.g. a rubber tube attached to a tap or a shower fitting without a check valve facility left lying in dirty bath water.

Notes:
(1) Servicing valves to be provided on supply pipes to storage and flushing cisterns.
(2) Copper tube pipe sizes shown.

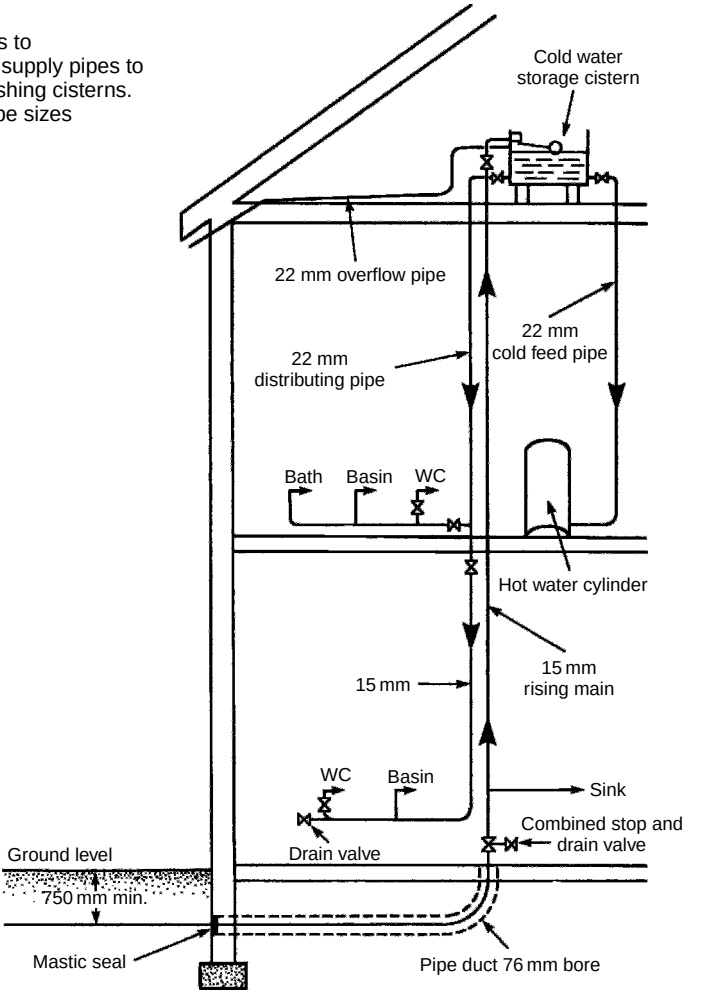


Ref.: The Water Supply (Water Fittings) Regulations 1999.

Indirect System of Cold Water Supply

The indirect system of cold water supply has only one drinking water outlet, at the sink. The cold water storage cistern has a minimum capacity of 230 litres, for location in the roof space. In addition to its normal supply function, it provides an adequate emergency storage in the event of water main failure. The system requires more pipework than the direct system and is therefore more expensive to install, but uniform pressure occurs at all cistern-supplied outlets. The water authorities prefer this system as it imposes less demand on the main. Also, with fewer fittings attached to the main, there is less chance of back siphonage. Other advantages of lower pressure include less noise and wear on fittings, and the opportunity to install a balanced pressure shower from the cistern.

Notes:
(1) Servicing valves to be provided on supply pipes to storage and flushing cisterns.
(2) Copper tube pipe sizes shown.



Ref.: The Water Supply (Water Fittings) Regulations 1999.

See also page 5.

Hardness in water occurs when calcium or magnesium salts are present. This is most common where water extraction is from boreholes into chalky strata or chalky aquifers.

Measurement

- Parts per million (ppm), i.e. milligrams per litre (mg/l) e.g.

Location	Typical ppm
Bristol	300
Cardiff	100
Hartlepool	460
London	285
Manchester	<60
Newcastle	160
Scotland	<50

For a general guide to England and Wales, see map on next page.

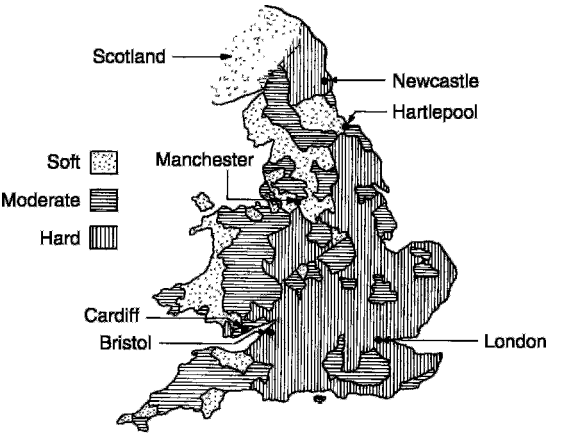
- Clarke's scale – a numerical classification, sometimes referred to as degrees Clarke.

Classification

Type of water	Clarkes	Approx. ppm
Soft	<3.5	<50
Moderately soft	3.5–7.0	50–100
Slightly hard	7.0–10.5	100–150
Moderately hard	10.5–14.0	150–200
Hard	14.0–21.0	200–300
Very hard	>21.0	>300

1 degree Clarke is about 1 part per 70 000.

When hard water is heated, the dissolved salts change to solids and deposit on the linings of pipework, boilers and other ancillaries. Kettle scale is an obvious example, but far more significant is its efficiency reduction of hot water and central heating plant. If enough scale is deposited, pipework systems can become completely blocked or `furred up'. This can have explosive consequences, as safety valves will also be affected. Chalk build up normally takes years, but in very hard water areas, it may be just a few months depending on the frequency of plant use. Hence the limitations of direct hot water systems (see page 37) where fresh water is continually introduced. Direct systems are only applicable where water hardness is less than 150 ppm and water temperatures do not exceed 65°C. The water temperature in modern hot water and heating systems exceeds 80°C, therefore direct systems are effectively obsolete in favour of indirect installations, (see page 38). Indirect systems have the same water circulating throughout the primary and heating pipework and it is only drained off during maintenance and repair.

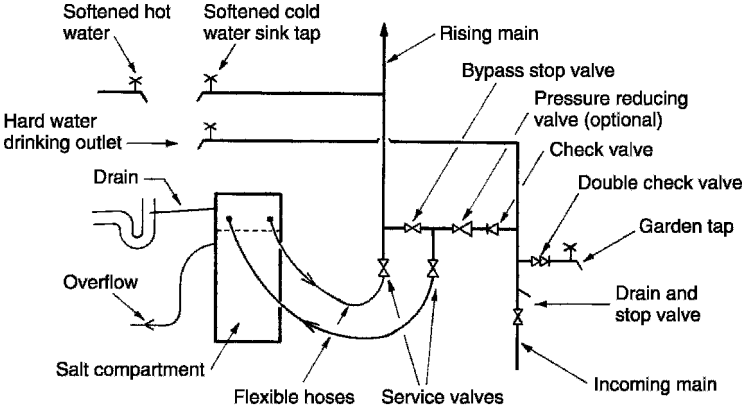


Guide to water hardness in England and Wales

Characteristics of hard water are:

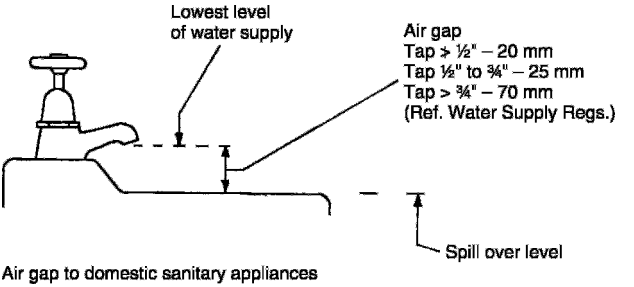
- difficult to create a lather with normal soap
- scum and tide marks in baths and basins
- chalk staining or streaking on washed glassware.

In hard water areas, these problems can be overcome with the installation of a water softener. These devices are relatively compact and will fit conveniently within the housing under a domestic sink. This location is ideal, as the housing will normally accommodate the rising water main and stop valve. It also provides simple access for replacement of salt granules or blocks. The unit contains a resin bed of sodium chloride or common salt. The salt exchanges calcium and magnesium ions for non-scale-forming sodium ions. Regeneration can be by electric timer, but most domestic softeners have an integral water volume metering device.



Typical installation of a domestic water softener

Domestic sanitary appliances – all potable (drinkable) water supplies must be protected against pollution by backflow or back siphonage from water that could be contaminated. Protection is effected by leaving sufficient space or air gap between the lowest point of the control device or tap discharge and the appliance spill over level.



Air gap to domestic sanitary appliances

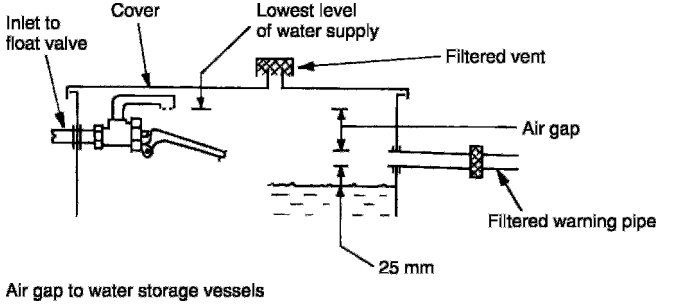
British Standard determination of air gap to domestic sanitary appliances:

- Single feed pipe, i.e. one tap, air gap ⩾20 mm or 2 × internal diameter of tap orifice (take greater value).
- Multiple feed pipe, i.e. hot and cold taps, air gap ⩾20 mm or 2 × sum of orifice diameters (take greater value).

For example, a bath with two taps of 20 mm internal diameter inlet orifice:

20 mm or 2 × (20 + 20 mm) = 80 mm. Air gap = 80 mm minimum.

Water cisterns or storage vessels – pipework supplying potable water must discharge into an unobstructed air gap between the regulating device water inlet to the vessel and the overflow or warning pipe.



Air gap to water storage vessels

In this situation the air gap should be ⩾20 mm or 2 × internal diameter of the regulating valve inlet orifice (take greater value).

For example, a 20 mm internal diameter orifice:

20 mm or 2 × 20 mm = 40 mm. Air gap = 40 mm minimum.

Refs: Water Supply (Water Fittings) Regulations.

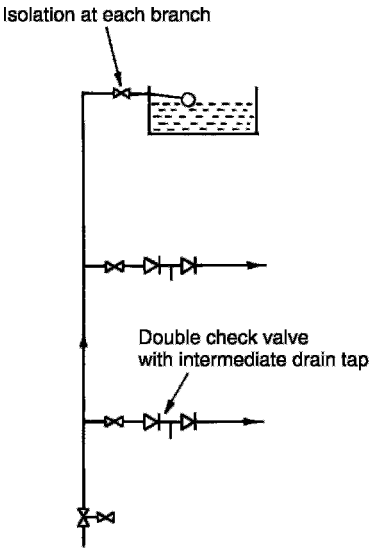
BS EN 1717: Protection against pollution of potable water in water installations and general requirements of devices to prevent pollution by backflow.

Secondary Backflow Protection

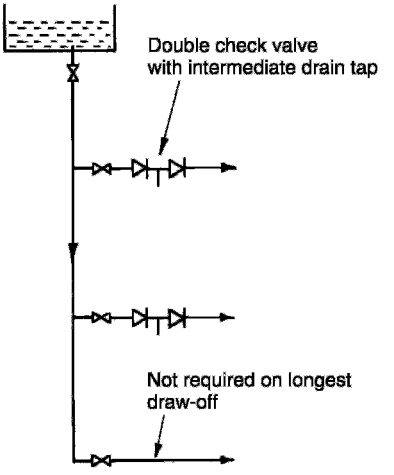
Secondary backflow or back siphonage protection is an alternative or supplement to the provision of air gaps. It is achieved by using mechanical devices such as double check valves or a vacuum breaker in the pipeline. Special arrangements of pipework with branches located above the spill level of appliances are also acceptable.

Ref: BS 6282, Devices with moving parts for the prevention of contamination of water by backflow.

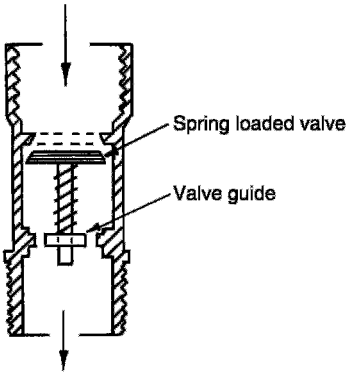
Typical applications – primary heating circuits, washing machines and garden taps.



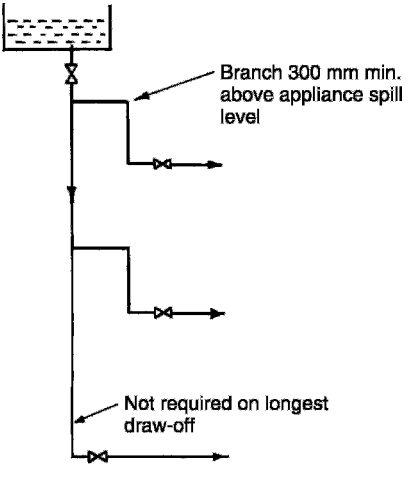
Direct mains water supply



Gravity distribution



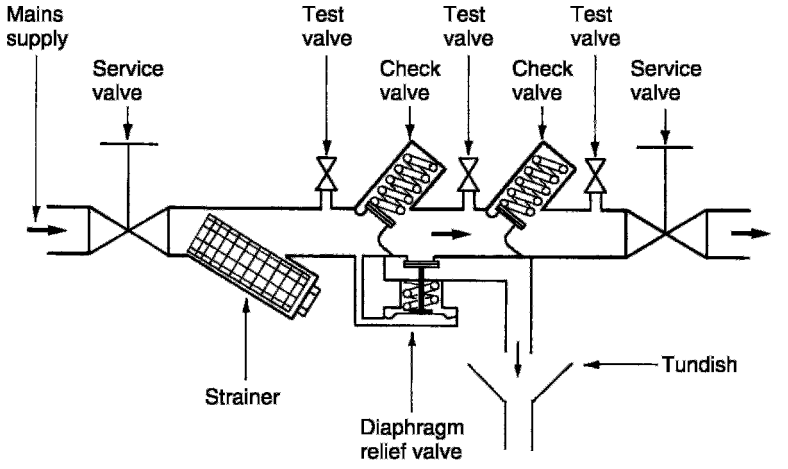
Check valve



Gravity distribution (alternative)

Mains water supply to commercial and industrial premises must be protected against the possibility of contamination by backflow. Where toxic processes exist, e.g. dyeing, chemical manufacture, insecticide preparation, car washing, irrigation systems, etc., it is imperative that the effects of a pressure reduction on drinking water supplies be contained.

Contamination of domestic water supply situations is prevented by installing double check valves to appliances or systems which could be a risk. In the interests of public health, the water authorities require greater security measures on mains supplies to industrial processes. Hitherto, a device containing two check valves with an intermediate pressure relief valve discharging visibly to a tundish has been considered adequate. Current requirements include a modification to verify or check through test points that the fitting is functioning correctly. This modified device is known as a 'Verifiable backflow preventer with reduced pressure zone'. It contains three pressure zones separated by differential obturators (two positively loaded check valves). Each pressure zone has a test point to verify that the valve is functioning correctly.



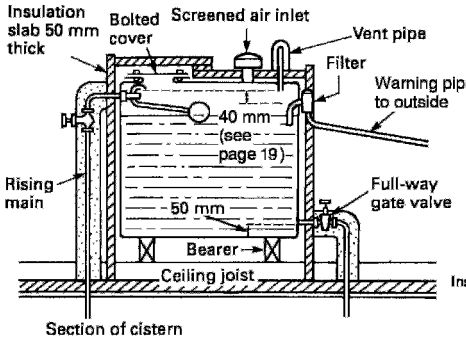
Operating principle and installation of a verifiable backflow prevention device with reduced pressure zone

Refs. The Water Supply (Water Fittings) Regulations.
BS EN 1717: Protection against pollution of potable water in water installations and general requirements of devices to prevent pollution by backflow.

Cisterns can be manufactured from galvanised mild steel (large non-domestic capacities), polypropylene or glass reinforced plastics. They must be well insulated and supported on adequate bearers to spread the concentrated load. Plastic cisterns will require uniform support on boarding over bearers. A dustproof cover is essential to prevent contamination.

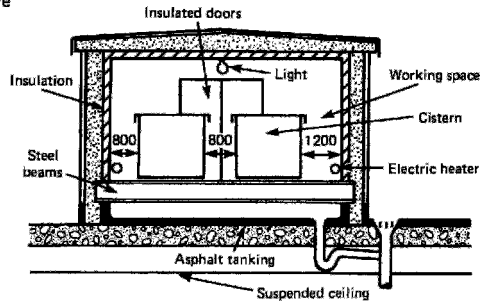
For large buildings, cisterns are accommodated in a purpose-made plant room at roof level or within the roof structure. This room must be well insulated and ventilated, and be provided with thermostatic control of a heating facility.

Where storage demand exceeds 4500 litres, cisterns must be duplicated and interconnected. In the interests of load distribution this should be provided at much lower capacities. For maintenance and repairs each cistern must be capable of isolation and independent operation.

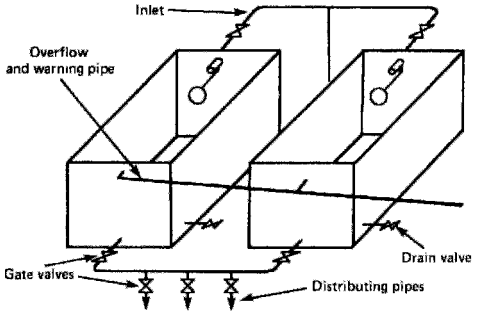


Section of cistern

Ref. BS 7181: Specification for storage cisterns up to 500 l actual capacity for water supply for domestic purposes.



Detail of cistern room



Duplicated cisterns

Refs. BS 417-2: Specification for galvanised low carbon steel cisterns, cistern lids, tanks and cylinders.
BS 4213: Cisterns for domestic use. Cold water storage and combined feed and expansion (thermoplastic) cisterns up to 500 l specification.

Cold water storage data is provided to allow for up to 24 hour interruption of mains water supply.

Building purpose	Storage/person/24 hrs	
Boarding school	90 litres	
Day school	30	
Department store with canteen	45	(3)
Department store without canteen	40	(3)
Dwellings	90	(1)
Factory with canteen	45	
Factory without canteen	40	
Hostel	90	
Hotel	135	(2) (3)
Medical accommodation	115	
Office with canteen	45	
Office without canteen	40	
Public toilets	15	
Restaurant	7 per meal	

Notes: (1) 115 or 230 litres min. see pages 15 and 16

(2) Variable depending on classification.

(3) Allow for additional storage for public toilets and restaurants.

At the design stage the occupancy of a building may be unknown. Therefore the following can be used as a guide:

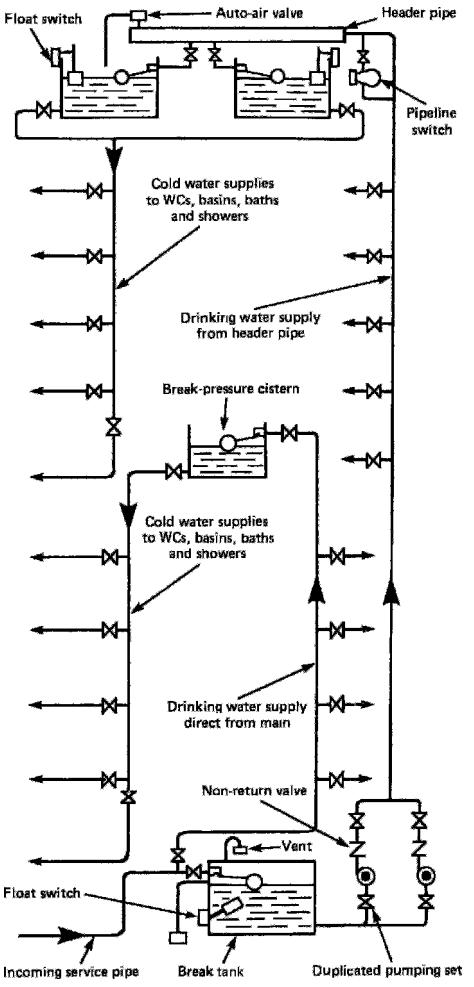
Building purpose	Occupancy
Dept. store	1 person per 30 m^2 net floor area
Factory	30 persons per WC
Office	1 person per 10 m^2 net floor area
School	40 persons per classroom
Shop	1 person per 10 m^2 net floor area

E.g. A 1000 m^2 (net floor area) office occupied only during the day therefore allow 10 hours' emergency supply.

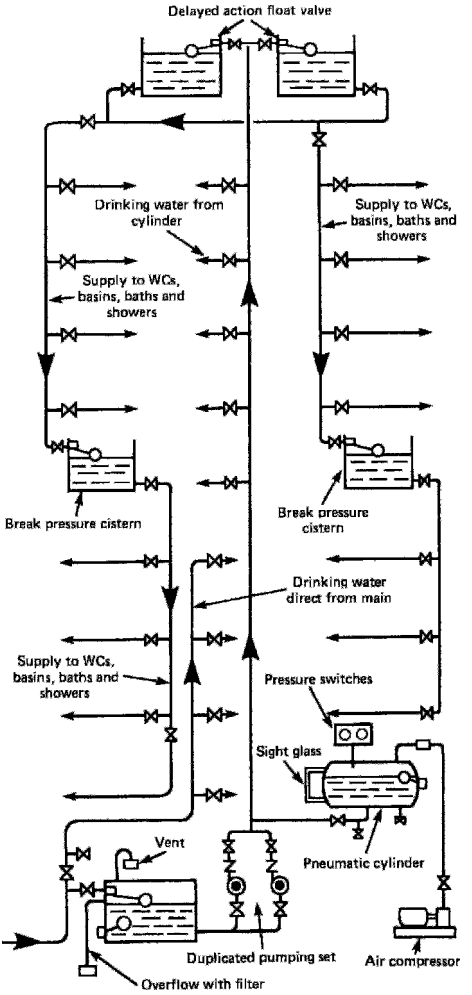
1000/10 = 100 persons × 40 litres = 4000 litres (24 hrs)
= 1667 litres (10 hrs)

Boosted Cold Water System – 1

For medium and high rise buildings, there is often insufficient mains pressure to supply water directly to the upper floors. Boosting by pump from a break tank is therefore usually necessary and several more of these tanks may be required as the building rises, depending on the pump capacity. A break pressure cistern is also required on the down service to limit the head or pressure on the lower fittings to a maximum of 30 m (approx. 300 kPa). The drinking water header pipe or storage vessel supplies drinking water to the upper floors. As this empties and the water reaches a predetermined low level, the pipeline switch engages the duty pump. A float switch in the break tank protects the pumps from dry running if there is an interruption to mains supply. The various pipe sections are fitted with isolating valves to facilitate maintenance and repairs.

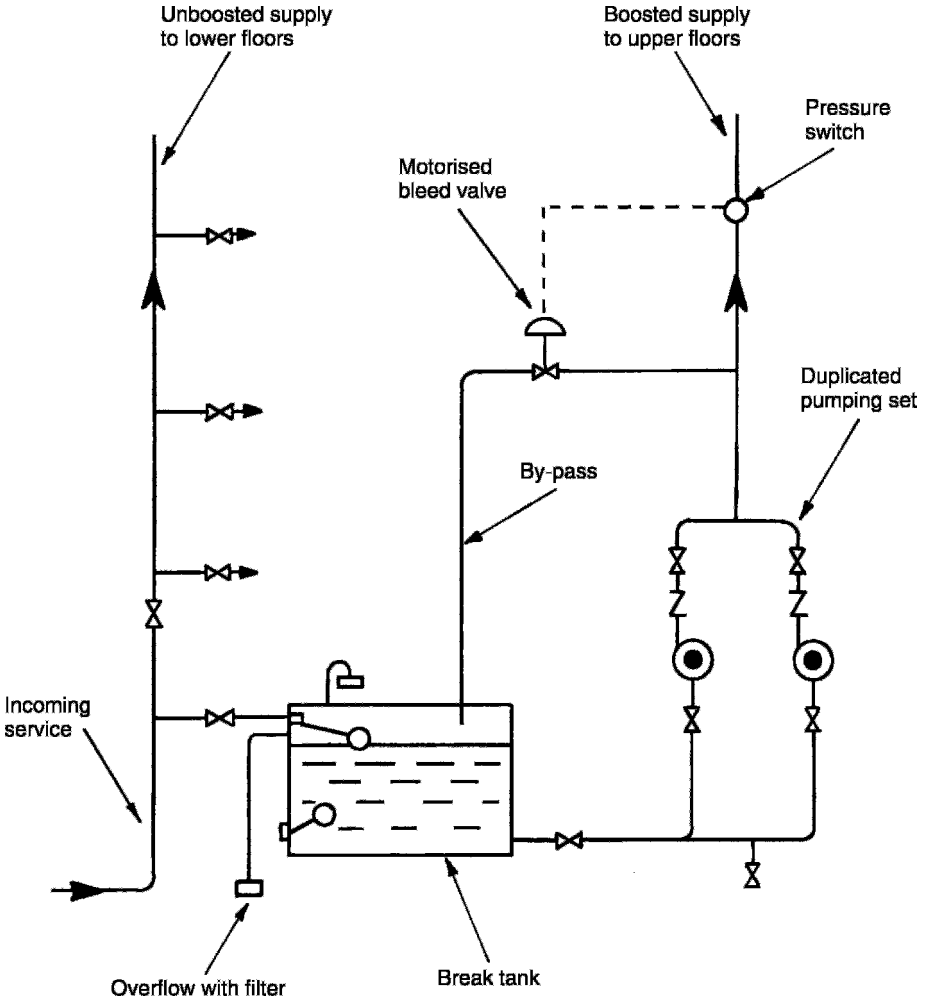


As an alternative to the drinking water header pipe, an auto-pneumatic cylinder may be used. Compressed air in the cylinder forces water up to the float valves and drinking water outlets on the upper floors. As the cylinder empties a low pressure switch engages the duty pump. When the pump has replenished the cylinder, a high pressure switch disengages the pump. In time, some air is absorbed by the water. As this occurs, a float switch detects the high water level in the cylinder and activates an air compressor to regulate the correct volume of air. Break pressure cisterns may be supplied either from the storage cisterns at roof level or from the rising main. A pressure reducing valve is sometimes used instead of a break pressure cistern.



Boosted Cold Water System – 3

In modest rise buildings of several storeys where water is in fairly constant demand, water can be boosted from a break tank by a continuously running pump. The installation is much simpler and less costly than the previous two systems as there is less need for specialised items of equipment. Sizing of the pump and its delivery rating are critical, otherwise it could persistently overrun, or at the other extreme be inadequate. Modern pumps have variable settings allowing considerable scope around the design criteria. The pump is normally scheduled to run on a timed programme, e.g. in an office block it may commence an hour before normal occupancy and run on for a couple of hours after. Water delivery should be just enough to meet demand. When demand is low a pressure regulated motorised bleed valve opens to recirculate water back to the break tank.

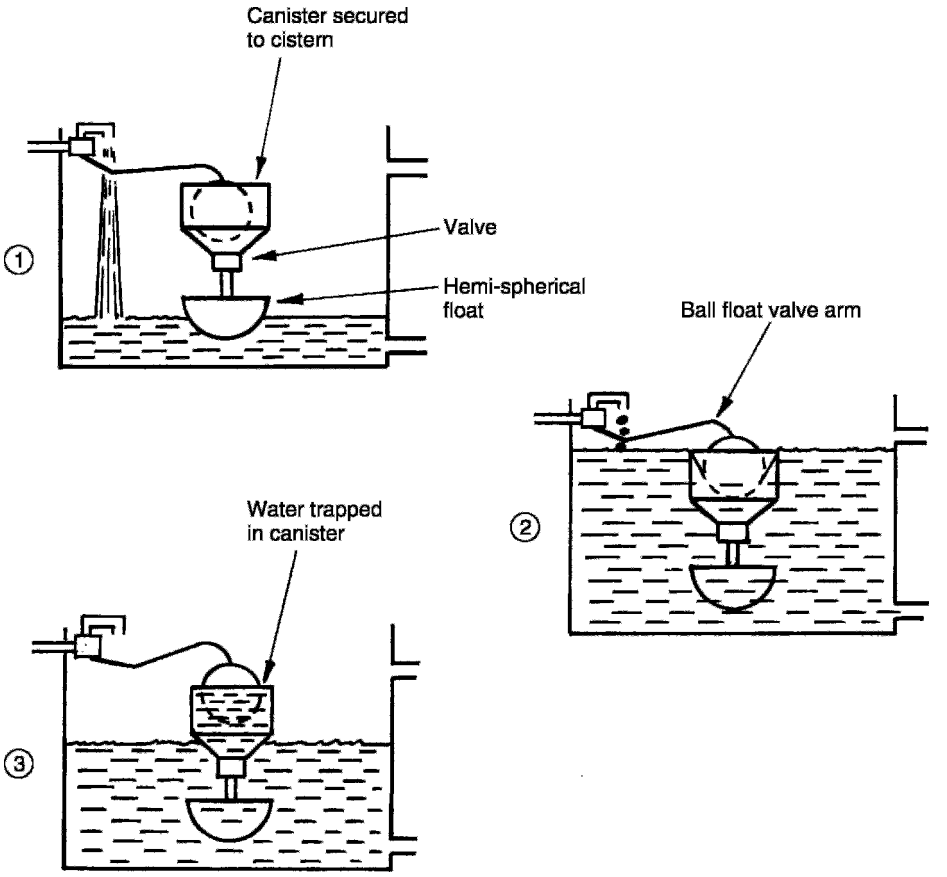


If normal float valves are used to regulate cistern water supply from an auto-pneumatic cylinder (page 25), then cylinder and pump activity will be frequent and uneconomic. Therefore to regulate activity and deliveries to the cistern, a delayed action float valve mechanism is fitted to the storage cistern.

Stage 1. Water filling the cistern lifts hemi-spherical float and closes the canister valve.

Stage 2. Water overflows into the canister, raises the ball float to close off water supply.

Stage 3. As the cistern empties, the ball float remains closed until low water level releases the hemi-spherical float. As this float valve drops, water is released from the canister to open the ball float valve to replenish the cistern from the pneumatic supply.

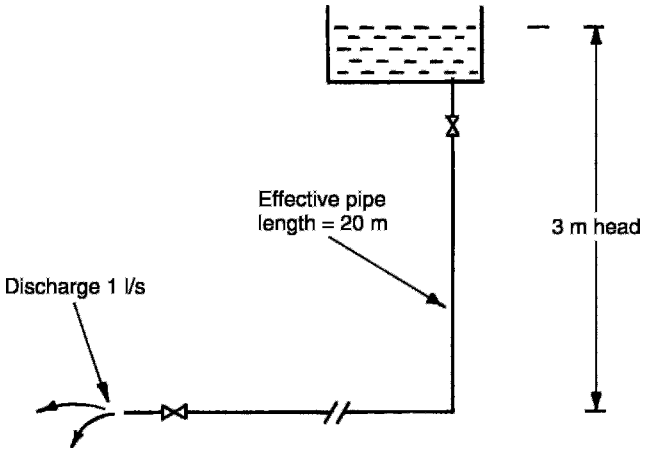


Thomas Box formula:

$$d = \sqrt[5]{\frac{q^2 \times 25 \times L \times 10^5}{H}}$$

where: d = diameter (bore) of pipe (mm)
q = flow rate (l/s)
H = head or pressure (m)
L = length (effective) of pipe (m)
(actual length + allowance for bends, tees, etc.)

e.g.



$$d = \sqrt[5]{\frac{(1)^2 \times 25 \times 20 \times 10^5}{3}}$$

$$d = \sqrt[5]{16\,666\,667} = 27{\cdot}83 \text{ mm}$$

The nearest commercial size above this is 32 mm bore steel or 35 mm outside diameter copper.

Note: Head in metres can be converted to pressure in kPa by multiplying by gravity, e.g. 3 m × 9.81 = 29.43 kPa (approx. 30 kPa).

Steel pipe (inside dia.)		Copper tube (mm)		Polythene (mm)	
Imperial (")	Metric (mm)	Outside dia.	Bore	Outside dia.	Bore
$\frac{1}{2}$	15	15	13·5	20	15
$\frac{3}{4}$	20	22	20	27	22
1	25	28	26	34	28
$1\frac{1}{4}$	32	35	32	42	35
$1\frac{1}{2}$	40	42	40		
2	50	54	51·5		
$2\frac{1}{2}$	65	67	64·5		
3	80	76	73·5		

Approximate equivalent pipe lengths of some fittings (m).

Pipe bore (mm)	Elbow	Tee	Stop valve	High pressure float valve
15	0·6	0·7	4·5	75
20	0·8	1·0	7	50
25	1·0	1·5	10	40
32	1·4	2·0	13	35
40	1·7	2·5	16	21
50	2·3	3·5	22	20

Notes: Figure given for a tee is the change of direction; straight through has no significant effect. These figures are only intended as a guide, they will vary between materials and design of fittings.

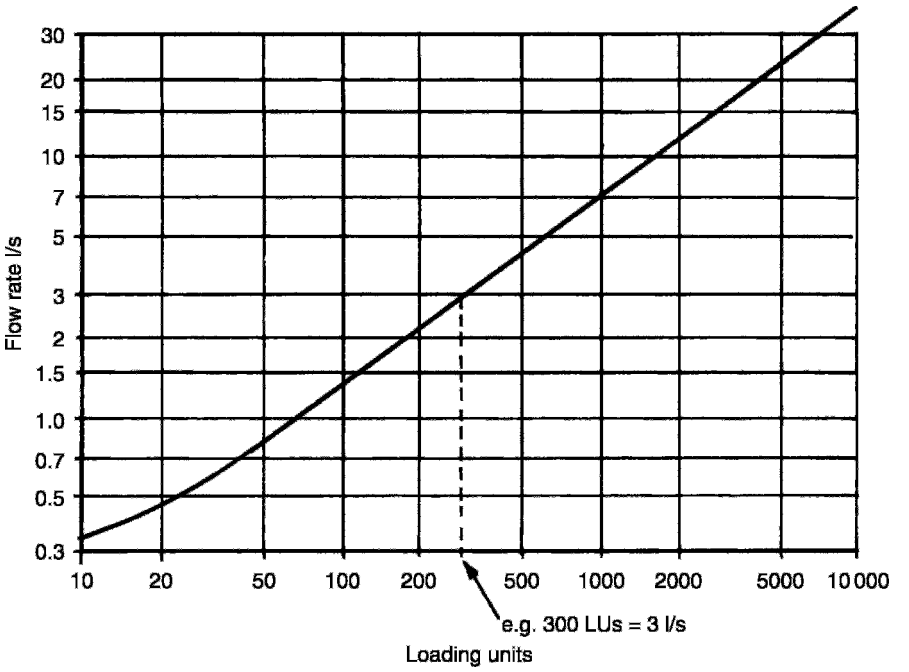
Recommended flow rates for various sanitary appliances (litres/sec)

WC cistern	0·11
Hand basin	0·15
Hand basin (spray tap)	0·03
Bath (19 mm tap)	0·30
Bath (25 mm tap)	0·60
Shower	0·11
Sink (13 mm tap)	0·19
Sink (19 mm tap)	0·30
Sink (25 mm tap)	0·40

Loading units are factors which can be applied to a variety of appliances. They have been established by considering the frequency of use of individual appliances and the desired water flow rate.

Appliance	Loading units
Hand basin	1·5 to 3 (depends on application)
WC cistern	2
Washing machine	3
Dishwasher	3
Shower	3
Sink (13 mm tap)	3
Sink (19 mm tap)	5
Bath (19 mm tap)	10
Bath (25 mm tap)	22

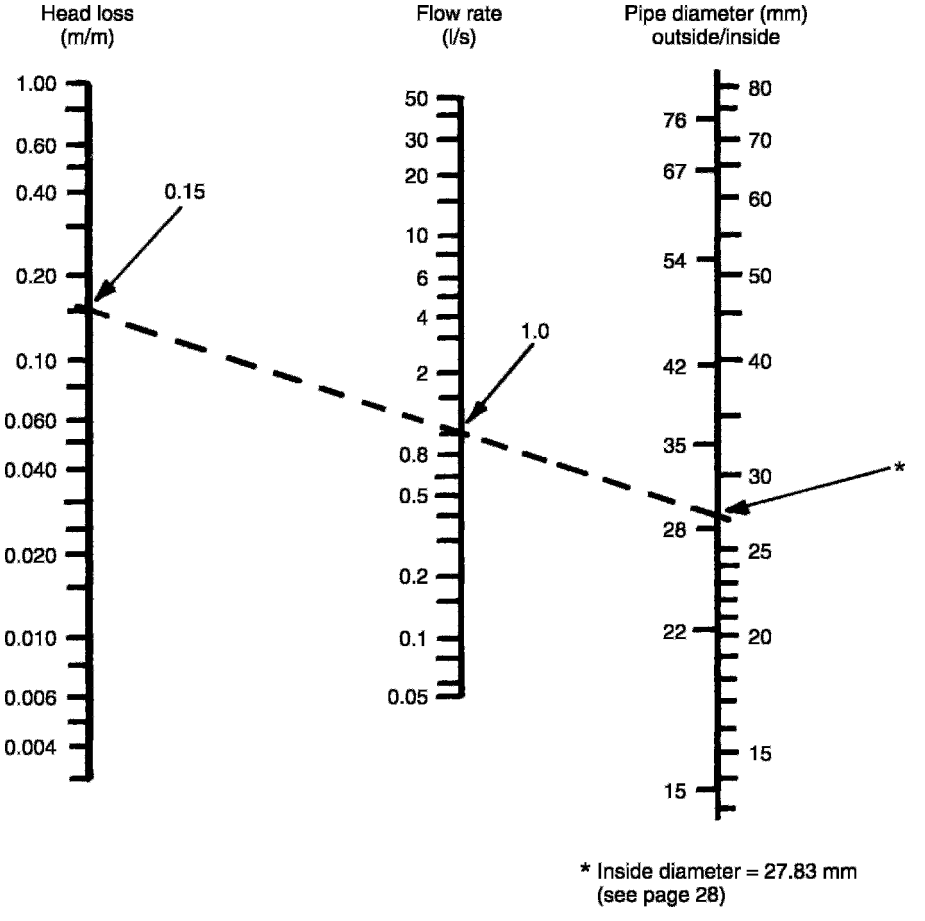
By determining the number of appliances on a pipework system and summating the loading units, an equivalent flow in litres per second can be established from the following conversion graph:



Pressure or head loss in pipework systems can be expressed as the relationship between available pressure (kPa) or head (m) and the effective length (m) of pipework. The formula calculation on page 28 can serve as an example:

Head = 3 m. Effective pipe length = 20 m. So, 3/20 = 0·15 m/m

By establishing the flow rate from loading units or predetermined criteria (1 l/s in our example), a nomogram may be used to obtain the pipe diameter. The chart below is for illustration and general use. For greater accuracy, pipe manufacturers' design data should be consulted for different materials and variations in water temperatures.



Ref. BS 6700: Specification for design, installation, testing and maintenance of services supplying water for domestic use within buildings and their curtilage.

Hydraulics is the experimental science concerning the study of energy in fluid flow. That is, the force of pressure required to overcome the resistance to fluid flowing through pipes, caused by the friction between the pipe and liquid movement.

The total energy of the liquid flowing in a pipe declines as the pipe length increases, mainly due to friction between the fluid and the pipe wall. The amount of energy or pressure loss will depend on:

- Smoothness/roughness of the internal pipe wall.
- Diameter of pipe or circumference of internal pipe wall.
- Length of pipe.
- Velocity of fluid flow.
- Amount of turbulence in the flow.
- Viscosity and temperature of fluid.

Theories relating to pressure loss by fluids flowing in pipes are diverse, but an established relationship is that the pressure losses (h) caused by friction are proportional to the square of the velocity of flow (v):

$$h \propto v^2$$

From this, for a pipe of constant size it can be seen that by developing the proportional relationship, a doubling (or more) of pressure will increase the velocity accordingly:

h (m)	v (m/s)
4	1·5
8	2·12 (1·5 × √2)
12	2·60 (1·5 × √3)
16	3·00 (1·5 × √4) or (2·12 × √2)
24	3·66 (1·5 × √6) or (2·60 × √2)
32	4·24 (1·5 × √8) or (3·00 × √2) etc., etc.

Also, it can be shown that if the condition (temperature and viscosity) of a fluid in a pipe remains constant, the discharge through that pipe is directly proportional to the square root of the fifth power of its diameter:

$$\sqrt{d^5}$$

This relationship can be identified in the Thomas Box pipe sizing formula shown on page 28.

Reynolds number – a coefficient of friction based on the criteria for similarity of motion for all fluids. Relevant factors are related by formula:

$$\frac{\text{density} \times \text{velocity} \times \text{linear parameter (diameter)}}{\text{viscosity}}$$

This is more conveniently expressed as:

$$R = \frac{\rho v d}{\mu}$$

Where: R = Reynolds number
ρ = fluid density (kg/m^3)
v = velocity (m/s)
d = diameter of pipe (m)
μ = viscosity of the fluid (Pa s) or (Ns/m^2)

Whatever the fluid type or temperature, an R value of less than 2000 is considered streamline or laminar. A value greater than 2000 indicates that the fluid movement is turbulent.

E.g. 1. A 12 mm diameter pipe conveying fluid of density 1000 kg/m^3 and viscosity of 0·013 Pa s at 2 m/s flow velocity has a Reynolds number of:

$$\frac{1000 \times 2 \times 0{\cdot}012}{0{\cdot}013} = 1846 \text{ (streamline flow)}$$

D'Arcy formula – used for calculating the pressure head loss of a fluid flowing full bore in a pipe, due to friction between fluid and pipe surface.

$$h = \frac{4 f L v^2}{2 g d}$$

Where: h = head loss due to friction (m)
f = coefficient of friction
L = length of pipe (m)
v = average velocity of flow (m/s)
g = gravitational acceleration (9.81 m/s^2)
d = internal diameter of pipe (m)

Note: `f', the D'Arcy coefficient, ranges from about 0·005 (smooth pipe surfaces and streamline flow) to 0·010 (rough pipe surfaces and turbulent flow). Tables can be consulted, although a mid value of 0·0075 is appropriate for most problem solving.

E.g. 2. A 12 mm diameter pipe, 10 m long, conveying a fluid at a velocity of flow of 2 m/s

$$\text{Head loss} = \frac{4 \times 0{\cdot}0075 \times 10 \times 2^2}{2 \times 9{\cdot}81 \times 0{\cdot}012} = 5{\cdot}09 \text{ m}$$

Depending on the data available, it is possible to transpose the D'Arcy formula for other purposes. For example, it may be used to calculate pipe diameter in this format:

$$d = \frac{4 f L v^2}{2 g h}$$

Flow rate (Q) – the discharge rate or flow rate of a fluid in a pipe is expressed as the volume in cubic metres (V) flowing per second (s). Q (m^3/s) is dependent on the pipe cross-sectional area dimensions (m^2) and the velocity of fluid flow (m/s). Q may also be expressed in litres per second, where 1 m^3/s = 1000 l/s.

A liquid flowing at an average velocity (v) in a pipe of constant area (A) discharging a length (L) of liquid every second (s), has the following relationship:

$Q = V \div s$ where $V = L \times A$ and $v = L \div s$

So, $Q = L \times A \div s$ where $v = L \div s$, $\therefore$ $Q = v \times A$

Q = flow rate (m^3/s), v = velocity of flow (m/s) and
A = cross-sectional area of pipe (m^2)

E.g. 1. The quantity of water flowing through a 12 mm diameter pipe at 2 m/s will be:

$Q = v \times A$, where $A = \pi r^2$
$Q = 2 \times 0{\cdot}000113 = 0{\cdot}000226$ m^3/s or 0·226 l/s

Relative discharge of pipes – this formula may be used to estimate the number of smaller branch pipes that can be successfully supplied by one main pipe:

$$N = \sqrt{(D \div d)^5}$$

where N = number of short branch pipes
D = diameter of main pipe (mm)
d = diameter of short branch pipes (mm)

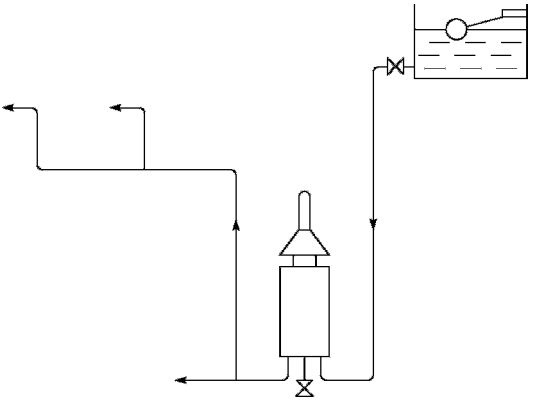
E.g. 2. The number of 32 mm short branch pipes that can be served from one 150 mm main will be:

$$N = \sqrt{(150 \div 32)^5} = 47$$

E.g. 3. The size of water main required to supply 15, 20 mm short branch pipes will be by formula transposition:

$D = d \sqrt[5]{N^2}$
$D = 20 \sqrt[5]{15^2} = 59$ (65 mm nearest standard)

2 HOT WATER SUPPLY SYSTEMS



DIRECT SYSTEM OF HOT WATER SUPPLY
INDIRECT SYSTEM OF HOT WATER SUPPLY
UNVENTED HOT WATER STORAGE SYSTEM
EXPANSION AND TEMPERATURE RELIEF VALVES
HOT WATER STORAGE CYLINDERS
PRIMATIC HOT WATER STORAGE CYLINDER
MEDIUM AND HIGH RISE BUILDING SUPPLY SYSTEMS
TYPES OF BOILER
SECONDARY CIRCULATION
DUPLICATION OF PLANT
ELECTRIC AND GAS WATER HEATERS
SOLAR HEATING OF WATER
HOT WATER STORAGE CAPACITY
BOILER RATING
PIPE SIZING
PRESSURISED SYSTEMS
CIRCULATION PUMP RATING
LEGIONNAIRES' DISEASE IN HOT WATER SYSTEMS
SEDBUK
GALVANIC OR ELECTROLYTIC ACTION
WATER TREATMENT

Expansion of Water

Water expands with changes in temperature. At 4°C water is at its most dense. At temperatures below 4°C down to zero or freezing, water expands about 9% (approximately 1/10) by volume. This is why underground supplies require adequate ground cover and externally exposed water pipes require insulation to prevent damage. At temperatures between 4°C and 100°C or boiling, water expands by about 4% (approximately 1/25) by volume and is significantly less dense – see table below. This degree of expansion and reduction in density is the principle of convective water circulation in elementary hot water systems.

Temperature (°C)	Density (kg/m^3)
0	999.80
4	1000.00
10	999.70
20	998.20
30	995.00
40	992.20
50	987.50
60	983.20
70	977.50
80	971.80
90	965.60
100	958.00

The following formula can be used to calculate the amount that water expands in a hot water system:

$$E = C \times (\rho_1 - \rho_2) \div \rho_2$$

Where: E = expansion (m^3)

C = capacity or volume of water in system (m^3)

ρ_1 = density of water before heating (kg/m^3)

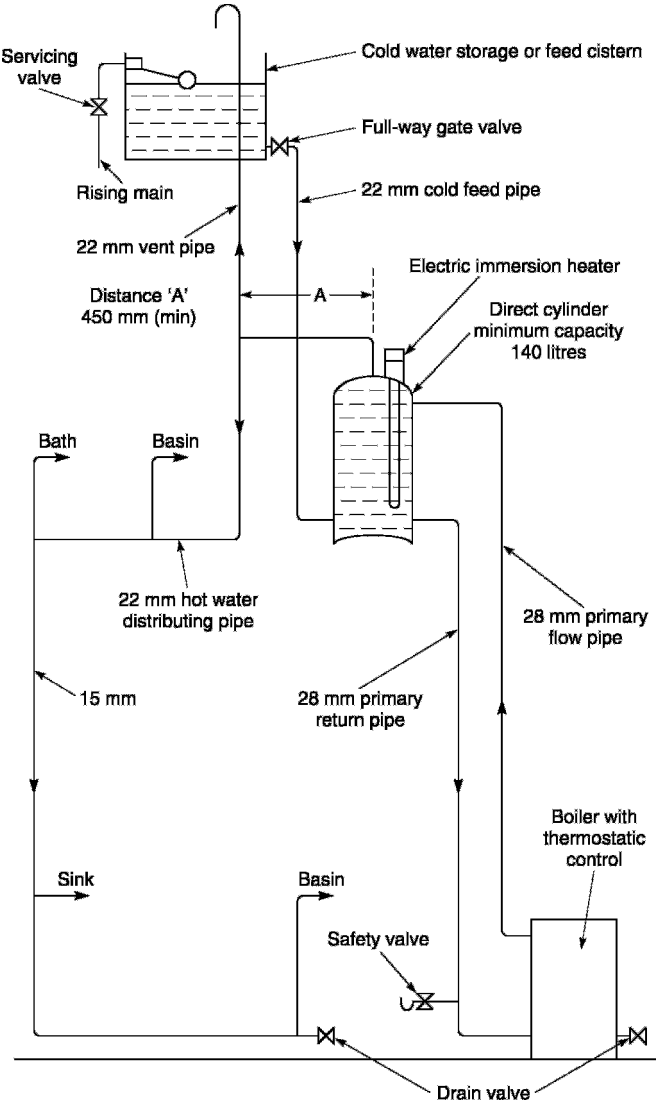
ρ_2 = density of water after heating (kg/m^3)

Example: A hot water system containing 15 m^3 of water, initially at 10°C to be heated to 80°C.

$$E = 15 \times (999.70 - 971.80) \div 971.80$$
$$E = 0.430 \text{ m}^3$$

Hot water and heating systems must incorporate a means for accommodating expansion. A fail safe mechanism must also be provided should the initial provision malfunction.

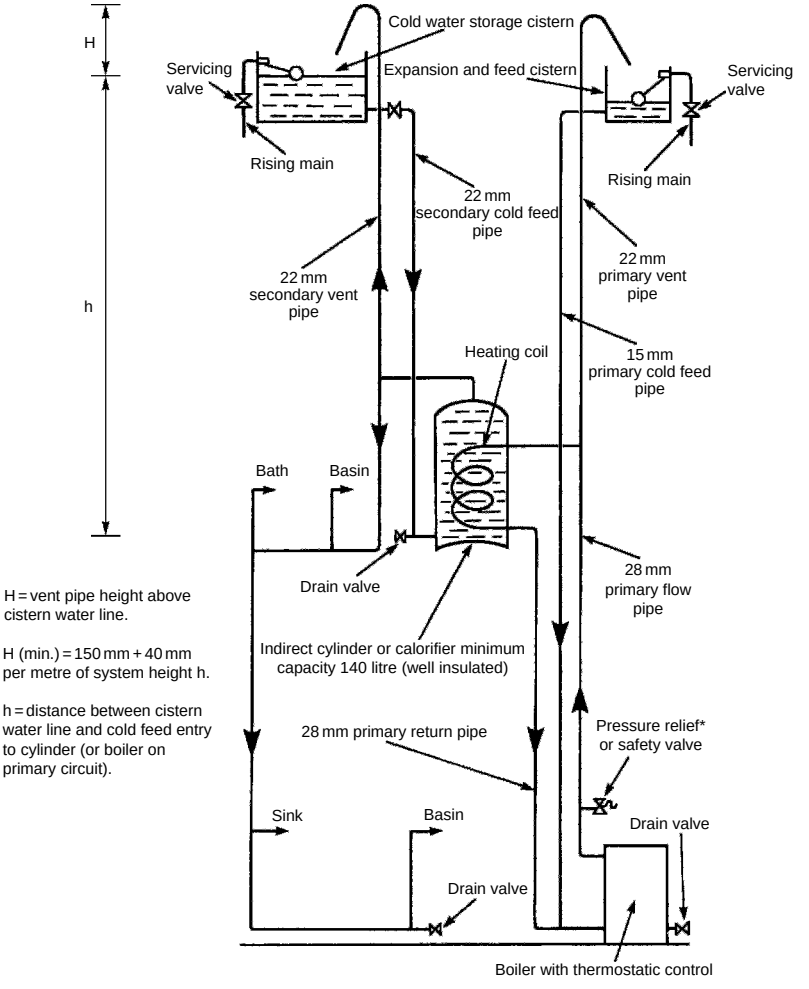
The hot water from the boiler mixes directly with the water in the cylinder. If used in a 'soft' water area the boiler must be rust-proofed. This system is not suited to 'hard' waters, typical of those extracted from boreholes into chalk or limestone strata. When heated the calcium precipitates to line the boiler and primary pipework, eventually 'furring up' the system to render it ineffective and dangerous. The storage cylinder and associated pipework should be well insulated to reduce energy losses. If a towel rail is fitted, this may be supplied from the primary flow and return pipes.



Note: All pipe sizes shown are for copper outside diameter.

Indirect System of Hot Water Supply

This system is used in 'hard' water areas to prevent scaling or 'furring' of the boiler and primary pipework. Unlike the direct system, water in the boiler and primary circuit is not drawn off through the taps. The same water circulates continuously throughout the boiler, primary circuit and heat exchange coil inside the storage cylinder. Fresh water cannot gain access to the higher temperature areas where precipitation of calcium would occur. The system is also used in combination with central heating, with flow and return pipes to radiators connected to the boiler. Boiler water temperature may be set by thermostat at about 80°C.

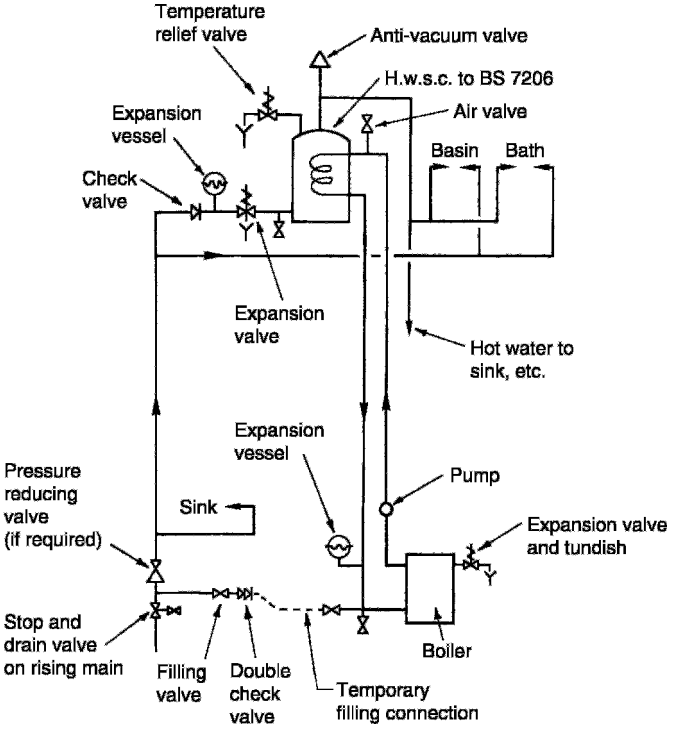


*A safety valve is not normally required on indirect open vent systems, as in the unlikely occurrence of the primary flow and vent becoming obstructed, water expansion would be accommodated up the cold feed pipe.

The Building Regulations, Approved Document J, permit the installation of packaged unit unvented hot water storage systems which have been accredited by the British Board of Agrément (BBA) or other European Organisation for Technical Approvals (EOTA) member bodies. Components should satisfy BS 7206: Specification for unvented hot water storage units and packages. A system of individual approved components is also acceptable. Safety features must include:

1. Flow temperature control between 60 and 65°C.
2. 95°C limit thermostat control of the boiler to close off the fuel supply if the working thermostat fails.
3. Expansion and temperature relief valves to operate at 95°C.
4. Check valves on water main connections.

The system is less space consuming than conventional systems and saves installation costs as there are no cold water storage and expansion cisterns. In addition to satisfying the Building Regulations, the local water authority should be consulted for approval and to ensure that there is adequate mains pressure.



Unvented system with hot water storage capacity in excess of 15 litres, with a sealed primary circuit

Installation – by suitably qualified person in possession of a registered operative identity card/certificate, issued by a recognised assessment body such as the Institute of Plumbing and Heating Engineering or the Construction Industry Training Board.

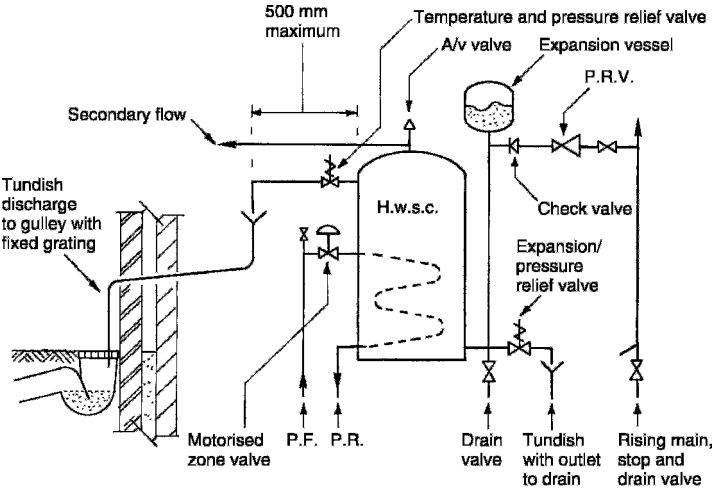
Notice of installation – given to the local authority Building Control Department. Building Regulation G3 – Hot Water Storage, requires a competent installer, precautions to prevent water temperature exceeding 100°C and any hot water discharge from safety devices to be conveyed safely and visibly.

Water supply – direct feed from water main, therefore no atmospheric vent pipe and no cold water storage cistern.

Water expansion – accommodated by suitably sized expansion vessel. Some units operate with an internal air gap (see next page).

Systems – direct heated by immersion heater, or indirect from a central heating boiler.

Storage cylinder materials – stainless steel, glass/vitreous enamel coated steel or heavy gauge copper.



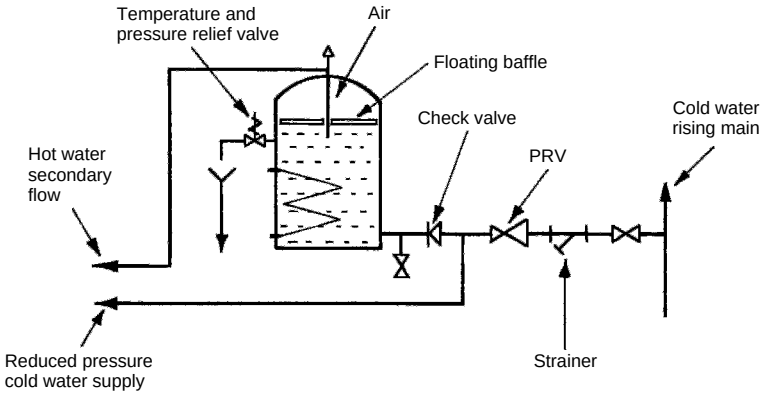
Unvented hot water storage cylinder and tundish detail

Controls –

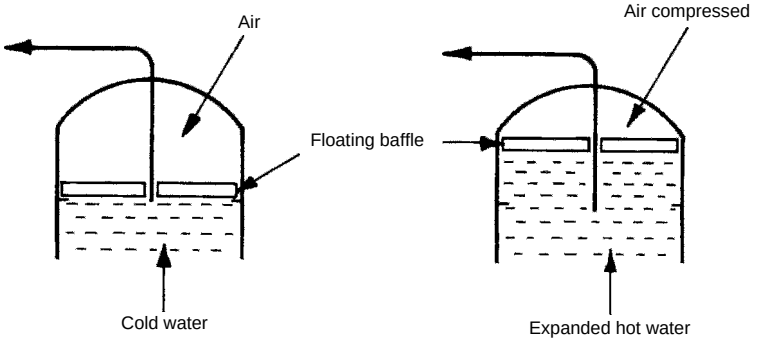
- Temperature and pressure relief valve.
- Expansion/pressure relief valve.
- Cylinder temperature regulating thermostat manually set to operate the zone valve at 60–65°C.
- Over-temperature cut out thermostat, pre-set to operate the zone valve at 85°C.

For all hot water systems, especially those exceeding 15 litres storage capacity, a purpose made hot water storage cylinder designed with provision for an `air gap' or `bubble top' is an effective alternative to installing a separate expansion vessel.

Typical installation –



Unvented hwsc incorporating an air gap



Function of the internal air gap

As the water expands on heating, the volume of trapped air is compressed to provide adequate delivery pressure and flow. After some time, the air may become depleted due to turbulence by water movement through the hot water storage cylinder. This will be noticed by the pressure relief valve discharging. The `air gap' is re-charged by draining the system and refilling. Some manufacturers fit a floating baffle between the water and the air, to reduce the effect of turbulence.

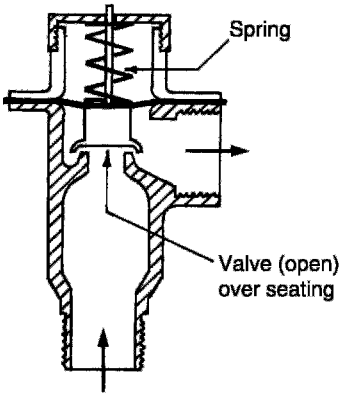
Expansion Valve and Temperature Relief Valve

Expansion devices in hot water systems are designed as a safe means for discharging water when system operating parameters are exceeded, i.e. in conditions of excess pressure and/or temperature.

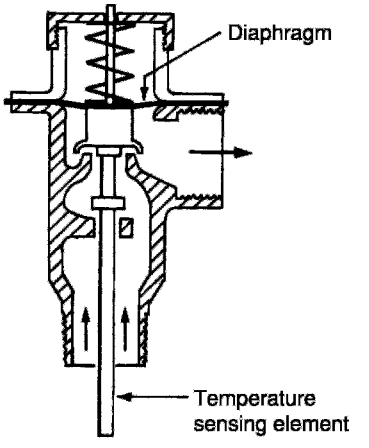
Expansion valve – Care should be taken when selecting expansion or pressure relief valves. They should be capable of withstanding 1.5 times the maximum pressure to which they are subjected, with due regard for water mains pressure increasing overnight as demand decreases.

Temperature relief valve – These should be fitted to all unvented hot water storage vessels exceeding 15 litres capacity. They are normally manufactured as a combined temperature and pressure relief valve. In addition to the facility for excess pressure to unseat the valve, a temperature sensing element is immersed in the water to respond at a pre-set temperature of 95°C.

Discharge from these devices should be safely controlled and visible, preferably over a tundish as shown on page 91.



Expansion valve



Temperature relief valve

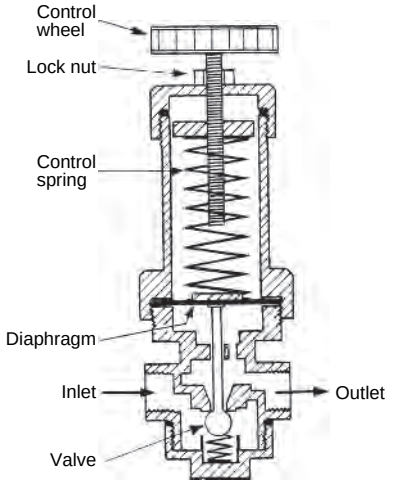
Ref. BS 6283-2: Safety and control devices for use in hot water systems. Specifications for temperature relief valves for pressures from 1 bar to 10 bar.

Pressure reducing valves are otherwise known as pressure regulators. PRV's can be applied to many different piped services including gas, compressed air, water and steam. These applications may range from relatively simple installations such as mains water supplied domestic unvented hot water storage systems, to larger scale industrial steam and district heating schemes.

High pressure is needed to overcome the resistances of long lengths of pipe distribution, changes in direction, valves, etc. For local distribution, the pressure must be reduced to:

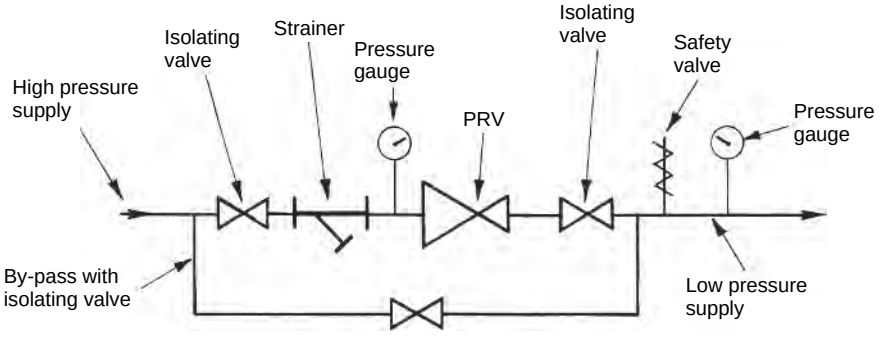
- Prevent undue wear and damage to the lighter gauge fittings and fixtures at the end use.
- Provide a maximum safe working pressure to prevent injury to end users.
- Regulate supplies at a constant value or desirable secondary pressure, irrespective of inlet pressure variations and changes in demand.

Function and installation



Typical PRV

- Outlet reduced pressure acts on the underside of the diaphragm.
- Control spring opposes the reduced pressure.
- Reduced pressure and control spring setting effect the position of the valve and flow condition.

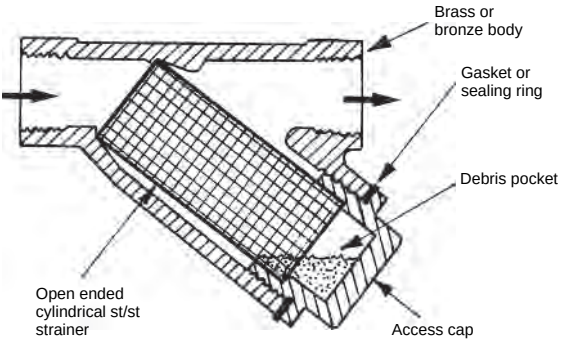


Installation to an industrial situation

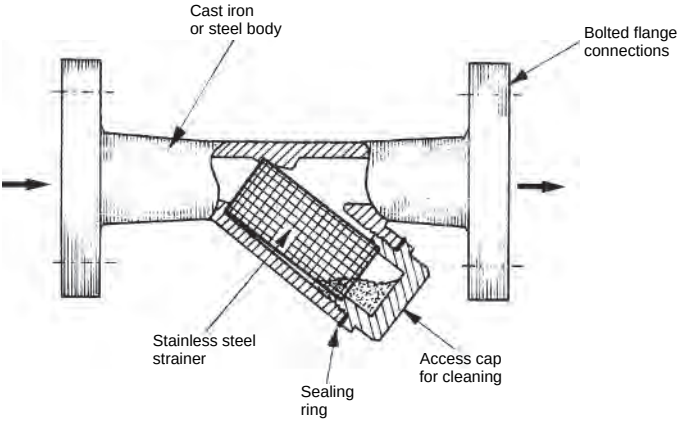
Strainers

A strainer is used to filter out and trap fluid suspended debris, pipe scale and carbonate deposits from hard water. This facility is essential to prevent component wear by erosion and abrasion, and interference with the efficient operation of pipe system controls. Strainers are a standard installation on processing plant and other industrial applications. There has been little need for strainers in domestic systems, until the use of items such as thermostatic mixing valves, shower mixers, check valves and pressure reducing valves have become standard. To protect the sensitivity of these units, most manufacturers integrate a means of filtering within the casting. Otherwise, an independent pipeline strainer of the type shown can be installed upstream of the unit.

Typical pipeline strainers



Threaded for domestic and light industrial services

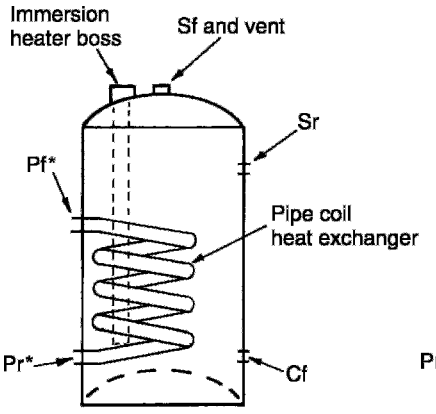


Flanged for industrial applications

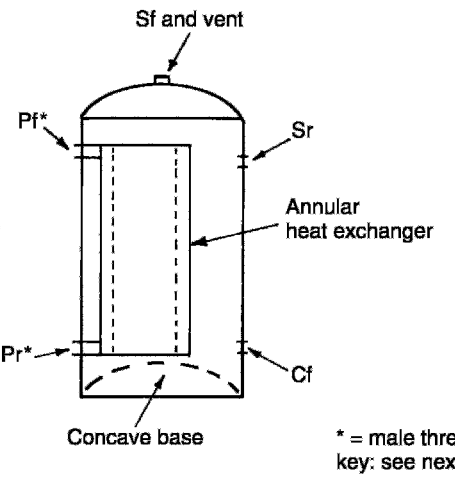
BS 1566-1: Copper indirect cylinders for domestic purposes. Open-vented copper cylinders. Requirements and test methods.

BS 1566-2: Copper indirect cylinders for domestic purposes. Specification for single feed indirect cylinders.

BS 417-2: Specification for galvanised low carbon steel cisterns, cistern lids, tanks and cylinders.



Indirect copper, 72–440 litres (domestic)



Indirect galvanised steel, 109–455 litres (domestic)

Direct cylinders have no coil or annular heat exchangers. They can be identified with female pipe threads for the primary flow and return connections. For domestic use: copper – 74 to 450 litres capacity, galvanised steel – 73 to 441 litres capacity. Direct and indirect cylinders for industrial and commercial applications are manufactured in copper and galvanised steel in capacities up to 4500 litres.

Notes:

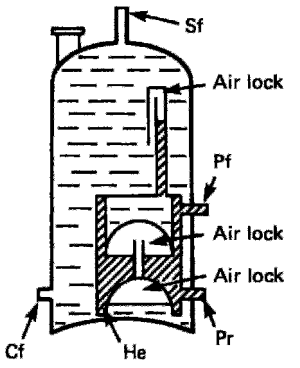
(1) Copper and galvanised (zinc plated) steel pipes and components should not be used in the same installation. In addition to electrolytic action between the dissimilar metals, pitting corrosion caused by tiny particles of dissolved copper settling on the galvanising will produce local cells which dissolve the zinc and expose the steel to rusting.

(2) Copper and galvanised steel cylinders normally incorporate an aluminium and a magnesium sacrificial anode, respectively. These are designed to deteriorate over sufficient time to allow a protective coating of lime scale to build up on the exposed surfaces.

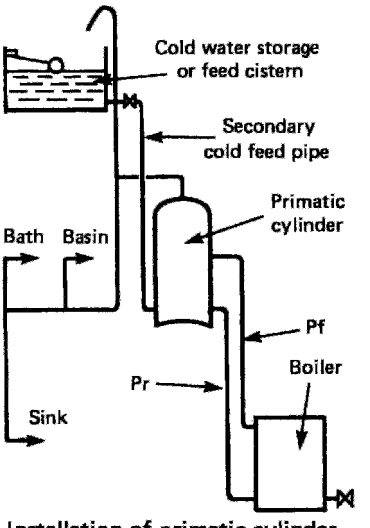
BS 1566-2: Specification for single feed indirect cylinders.

An indirect hot water system may be installed using a 'primatic' or single feed indirect cylinder. Conventional expansion and feed cistern, primary cold feed and primary vent pipes are not required, therefore by comparison, installation costs are much reduced. Only one feed cistern is required to supply water to be heated indirectly, by water circulating in an integral primary heater. Feed water to the primary circuit and boiler is obtained from within the cylinder, through the primary heater. The heat exchanger inside the cylinder has three air locks which prevent mixing of the primary and secondary waters. No corrosion inhibitors or system additives should be used where these cylinders are installed.

Key:
Sf = Secondary flow pipe
Pf = Primary flow pipe
Pr = Primary return pipe
He = Heat exchanger
Cf = Cold feed pipe

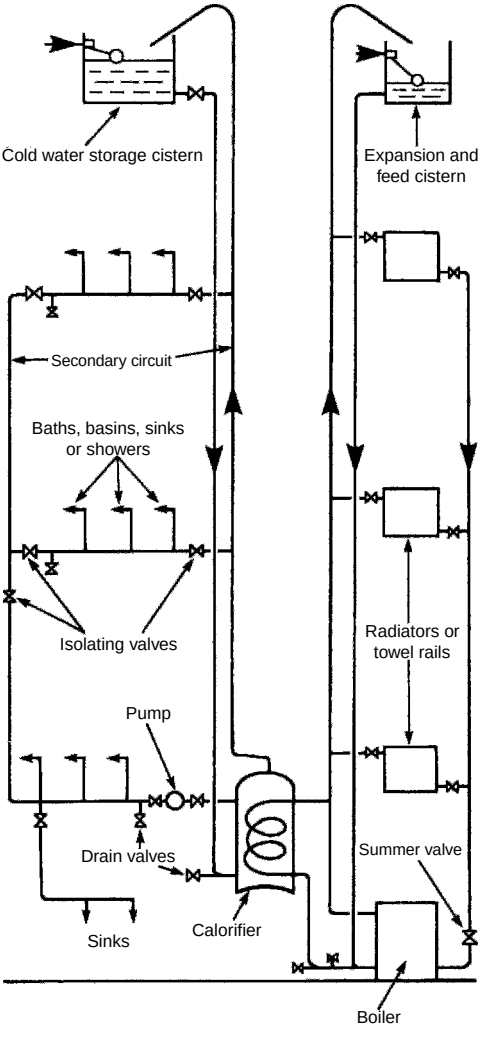


Primatic cylinder



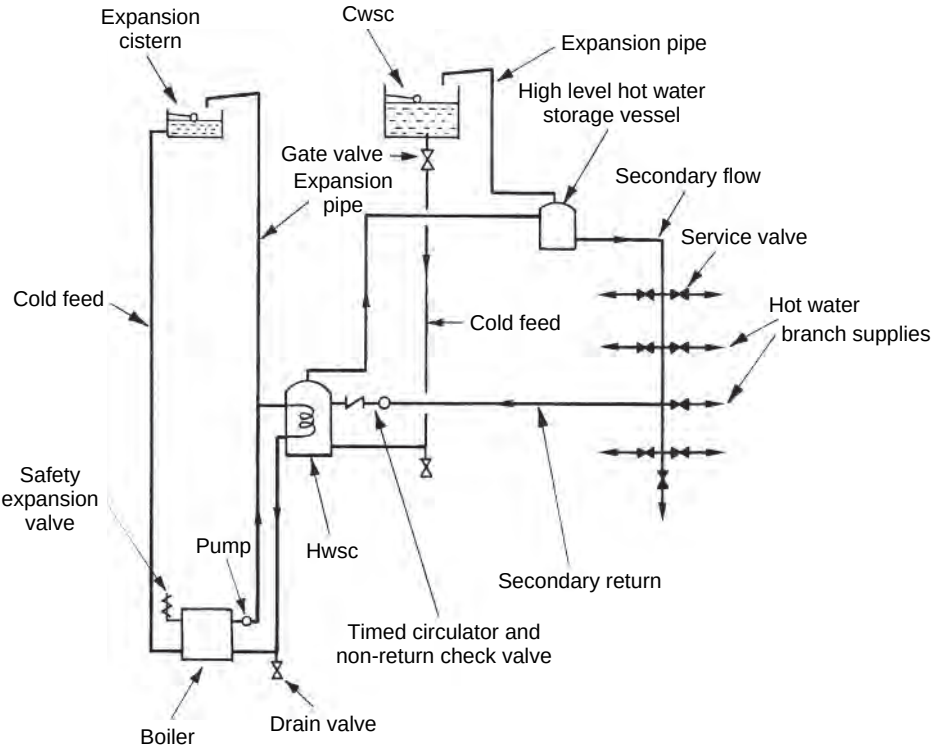
Installation of primatic cylinder

For larger buildings a secondary circuit will be required to reduce 'dead-legs' and to maintain an effective supply of hot water at all outlets. Convection or thermo-siphonage may provide circulation, but for a more efficient service a circulatory pump will be necessary. In buildings which are occupied for only part of the day, e.g. schools, offices, etc., a time control or programmer can be used to regulate use of the pump. Also, one of the valves near the pump should be motorised and automatically shut off with the pump and boiler when hot water is not required. All secondary circuits should be well insulated to reduce heat losses through the pipework. A heating installation can operate in conjunction with this system, but may require duplication of boilers or separate boilers for each function.



Indirect Supplementary Hot Water System

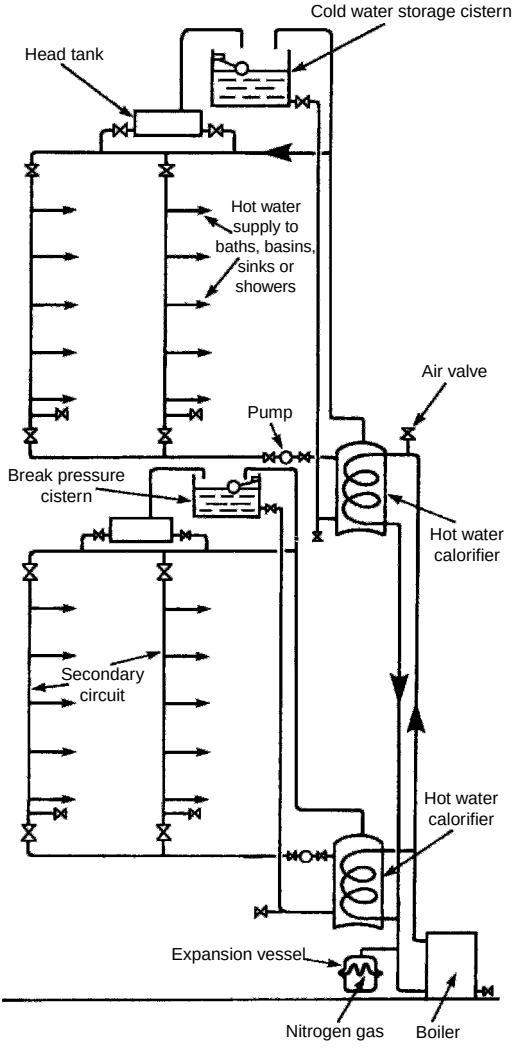
Hot water provision in moderately large buildings such as spacious houses, small hotels, hostels and other situations where demand is periodically high, can be from a large storage cylinder or cylinders installed in duplicate. Alternatively or additionally, depending on requirements, a supplementary storage vessel may be strategically located at high level. This vessel is relatively small, containing no more than 20% of the total design capacity.



Advantages over a single storage facility:

- Smaller secondary flow and return distribution pipes.
- Less concentrated dead load on the structure.

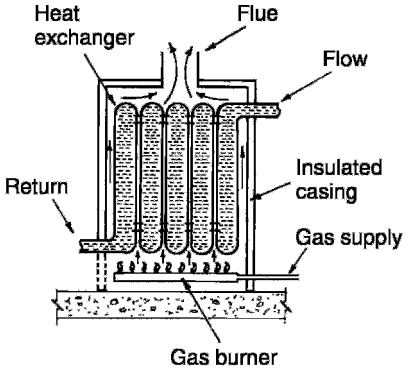
For convenience and to reduce wear on fittings, the maximum head of water above taps and other outlets is 30 m. This is achieved by using intermediate or break pressure cisterns for each sub-circuit. Head tanks are provided to ensure sufficient volume of stored hot water and adequate delivery to the upper floors. Compared with conventional installations a considerable amount of pipework and fitting time can be saved by using an expansion vessel to absorb expansion of water in the primary circuit. However, the boiler and calorifiers must be specified to a high quality standard to withstand the water pressure. All pipework and equipment must be well insulated.



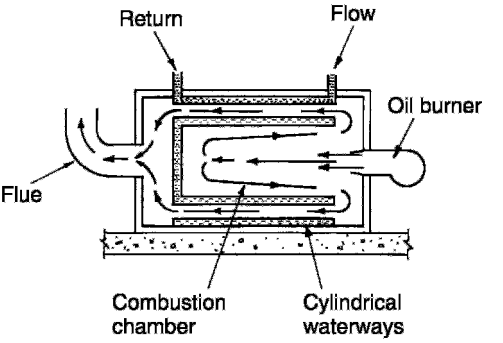
Cast iron sectional – made up of a series of hollow sections, joined together with left- and right-hand threaded nipples to provide the heat capacity required. When installed, the hollow sections contain water which is heated by energy transfer through the cast iron from the combusted fuel. Applications: domestic to large industrial boilers.

Steel shell, fire or flame tube – hot combusted fuel and gases discharge through multiple steel tubes to the extract flue. Heat energy from the burnt fuel transfers through the tube walls into cylindrical waterways. Tubes may be of annular construction with water surrounding a fire tube core. Uses: commercial and industrial buildings.

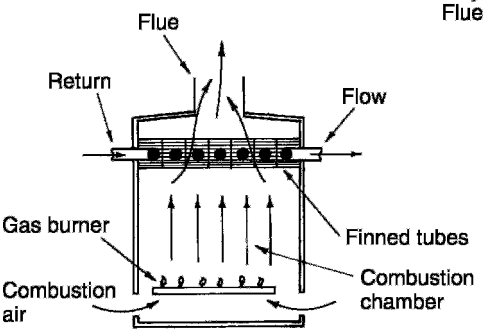
Copper or steel water tube – these reverse the principle of fire tubes. Water circulates in a series of finned tubes whilst the combusted fuel effects an external heat transfer. These are typical of the heat exchangers in domestic boilers.



Cast iron sectional boiler



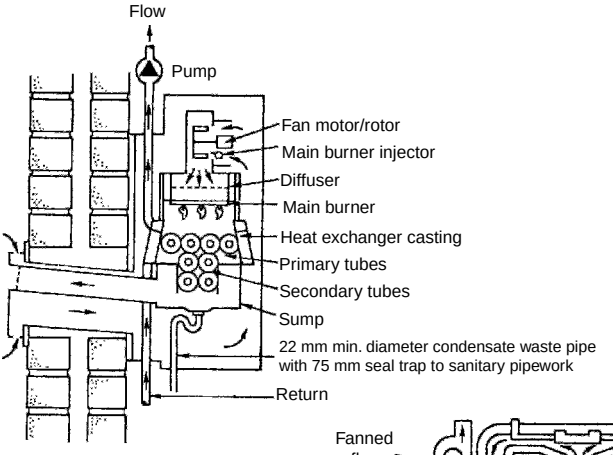
Fire tube boiler



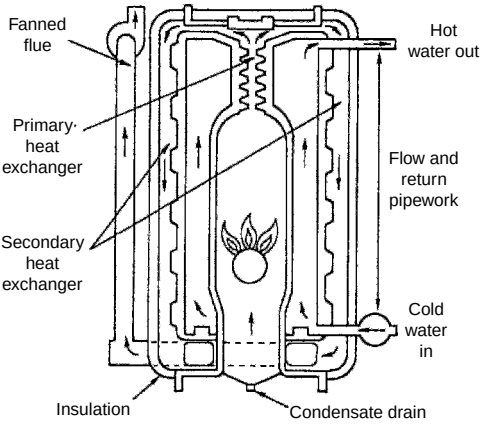
Water tube boiler

All of these boiler types may be fired by solid fuel, gas or oil.

Condensing boilers have a greater area of heat transfer surface than conventional boilers. In addition to direct transfer of heat energy from the burning fuel, heat from the flue gases is used as secondary heating to the water jacket. Instead of the high temperature (200–250°C) flue gases and water vapour discharging to atmosphere, they are recirculated around the water jacket by a fan. This fan must be fitted with a sensor to prevent the boiler firing in the event of failure. Condensation of vapour in the flue gases is drained to a suitable outlet. The overall efficiency is about 90%, which compares well with the 75% expected of conventional boilers. However, purchase costs are higher, but fuel savings should justify this within a few years.



Balanced flue condensing boiler



Conventional flue condensing boiler

Refs: BS 6798: Specification for installation of gas-fired boilers of rated input not exceeding 70 kWnet. Building Regulations, Approved Document H1: Foul Water Drainage, Section 1 – Sanitary pipework.

Condensing Gas Boilers – Characteristics (1)

Otherwise known as high efficiency boilers.

Originally developed in the 1930s. Lack of technological advances and less concern about effect of consuming fuel limited interest until the fuel crises of the 1970s.

Introduced to the domestic market in the early 1980s. Slow to establish due to relatively higher purchase cost. From 2005, virtually compulsory for new installations, to satisfy SEDBUK efficiency bands A and B.

Extracts heat from flue gases to gain from the secondary heating effect.

Heat exchanger must be corrosion resistant, i.e. stainless steel or aluminium to resist the acidity of condensate. Cast iron and copper are only suitable in non-condensing boilers with high flue gas temperatures which are unaffected by condensation.

Non-corrosive plastic condensate waste pipe required. Waste usually connected to a siphon which discharges condensate in one go from a 150 ml sump. This reduces the possibility of a drip discharge freezing.

Least efficient condensing boiler has about the same efficiency as the most efficient non-condensing boiler.

Condensing boilers are at their most efficient with low return water temperatures. This effects most condensation. Therefore, they are best used with modulating controls as described on page 120.

About 80% energy exchange occurs as combusted gas at temperatures above 200°C effect the primary heat exchange. The secondary heat exchange adds about another 5% as the fanned flue gases reduce to about 55°C as they pre-warm the returning system cool water. With this temperature reduction the flue gases condense, dew point occurs (steam turns to water) adding about another 5% in latent energy transfer.

The gas burner has to impart less energy to raise the temperature at the primary heat exchange, hence fuel savings and less CO_2 and NO_x emissions from the flue.

Controls –

Non-condensing boilers are efficiently controlled with thermostatic valves, thermostats and an interlock facility. The boiler is switched on and off relative to internal air temperature. High temperature water is delivered to emitters.

Condensing boilers are at their most efficient when enabled to run for sustained periods with a moderate flow water temperature and low return water temperature. They are ideally suited to modulating, weather compensated control systems.

Flue discharge has a distinct plume or cloud of moisture droplets. May be a problem with neighbouring properties.

Flue slopes back slightly towards the boiler to discharge any condensation from the flue duct into the condensate drain.

Typical SEDBUK factors:

Modern condensing boiler 88%
Modern non-condensing boiler 75%
Older boiler 58%

A non-condensing boiler loses at least 20% of heat energy produced into the flue. Therefore these boilers are 80% efficient at best. Approximately half the heat energy that would be otherwise lost in the flue is recovered by a condensing boiler. Therefore these boilers are approximately 90% efficient.

Approximate number of households in UK = 14 million.

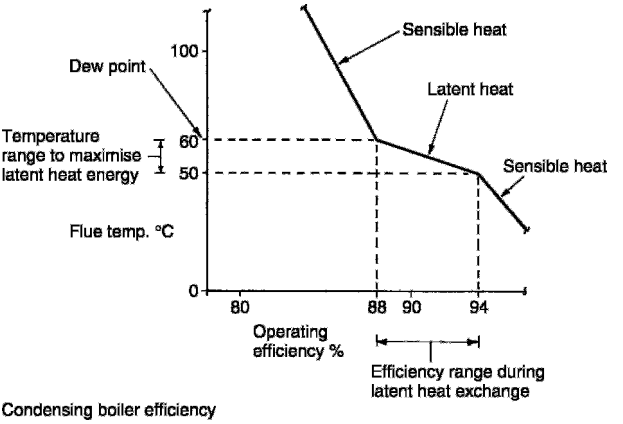
Typical annual household production of CO_2 with a non-condensing boiler = 5 tonnes.

Total potential CO_2 emissions = 70 million tonnes.

Typical annual household production of CO_2 with a condensing boiler = 3 tonnes.

Total potential CO_2 emissions = 42 million tonnes.

Therefore, in addition to fuel savings, condensing boilers represent a potential for an annual reduction in polluting or greenhouse gases of 28 million tonnes.

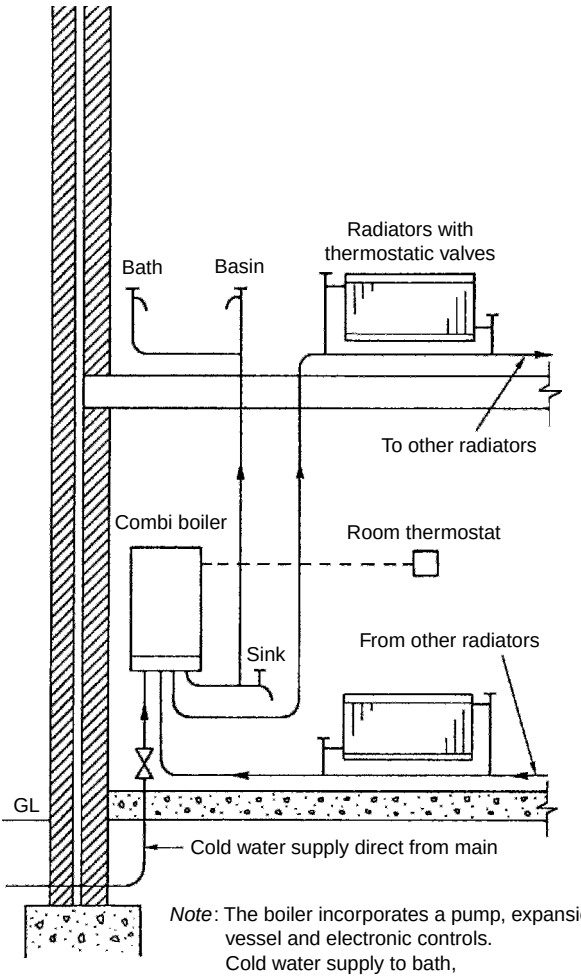


Condensing boiler efficiency

Note: Oil-fired condensing boilers are also marketed with specifications to satisfy current energy use requirements.

Combination Boiler

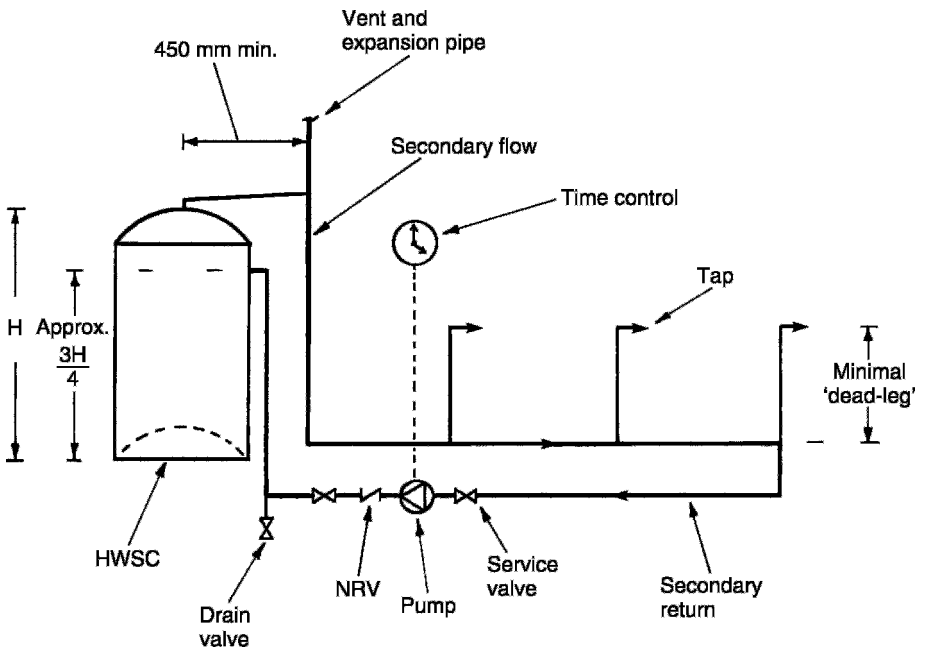
This system saves considerably in installation time and space, as there is no need for cisterns in the roof space, no hot water storage cylinder and associated pipework. The `combi' gas boiler functions as an instantaneous water heater only heating water as required, thereby effecting fuel savings by not maintaining water at a controlled temperature in a cylinder. Water supply is from the mains, providing a balanced pressure at both hot and cold water outlets. This is ideal for shower installations. Boiler location may be in the airing cupboard, leaving more space in the kitchen. The system is sealed and has an expansion vessel which is normally included in the manufacturer's pre-plumbed, pre-wired package for simple installation. Further control details are shown on page 113.



Note: The boiler incorporates a pump, expansion vessel and electronic controls. Cold water supply to bath, basin and sink has been omitted for clarity.

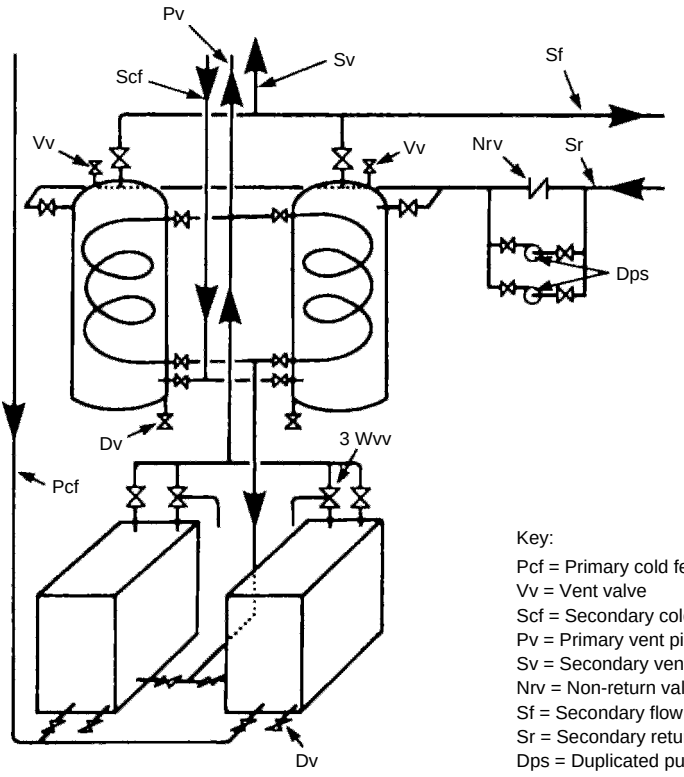
To prevent user inconvenience waiting for the cold water 'dead-leg' to run off and to prevent water wastage, long lengths of hot water distribution pipework must be avoided. Where cylinder to tap distances are excessive, a pumped secondary flow and return circuit may be installed with minimal 'dead-legs' branching to each tap. The pipework must be fully insulated and the circulation pump timed to run throughout the working day, e.g. an office system could be programmed with the boiler controls, typically 8.00 am to 6.00 pm, 5 days a week. A non-return valve prevents reverse circulation when the pump is not in use.

Nominal inside pipe dia. (mm)	Equivalent copper tube outside dia. (mm)	Max. length of secondary flow without a return (m)
10	12	20
>10 to 19	>12 to 22	12
>19 to 25	>22 to 28	8
>25	>28	3



Duplication of Plant

Dual installations or duplication of plant and equipment is required in buildings where operating efficiency is of paramount concern. With this provision, the supply of hot water in hotels, commercial buildings, offices, etc. is ensured at all times, as it is most unlikely that all items of plant will malfunction simultaneously. It may also be necessary to divide the design capacity of plant to reduce the concentration of structural loads. Each boiler and calorifier may be isolated for repair or renewal without disturbing the function of the others. Therefore when designing the system it is usual to oversize plant by up to one-third, to ensure the remaining plant has reasonable capacity to cope with demand. There is also the facility to economise by purposely isolating one boiler and calorifier during periods when a building is only part occupied.

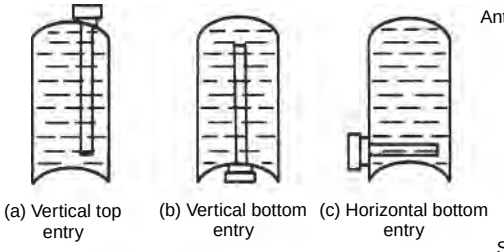


Duplicated plant

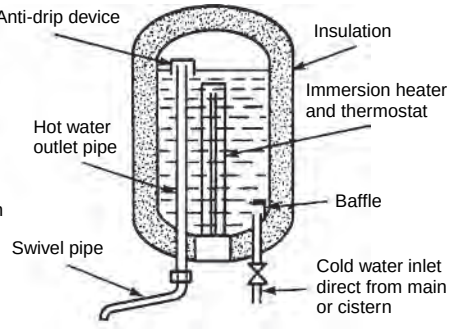
Key:

Pcf = Primary cold feed pipe
Vv = Vent valve
Scf = Secondary cold feed pipe
Pv = Primary vent pipe
Sv = Secondary vent pipe
Nrv = Non-return valve
Sf = Secondary flow pipe
Sr = Secondary return pipe
Dps = Duplicated pumps
3 Wvv = 3-way vent valve
Dv = Drain valve

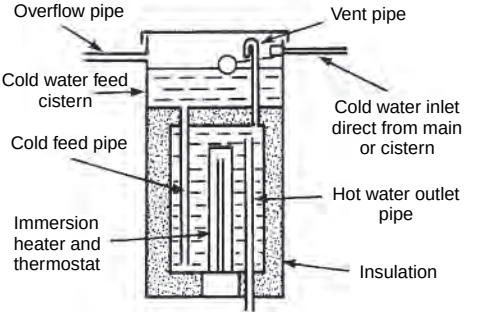
An electric immersion heater may be used within a conventional hot water storage cylinder. Alternatively, individual or self-contained open outlet heaters may be located over basins, baths or sinks. Combined cistern-type heaters can be used to supply hot water to several sanitary appliances. Energy conservation is achieved with an integral thermostat set between 60 and 65°C. This temperature is also sufficient to kill any bacteria. The immersion heater must be electrically earth bonded and the cable supplying the heating element must be adequate for the power load. A cable specification of 2·5 mm^2 is normally adequate with a 20 amp double pole control switch supplied direct from the consumer's unit or fuse box. Overload protection at the consumers unit is a 16 amp fuse or circuit breaker for a 3 kW element and 20 amp for a 4 kW element.



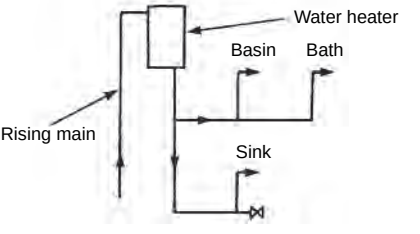
Positions of electric immersion heater inside cylinder



Self-contained open outlet heater



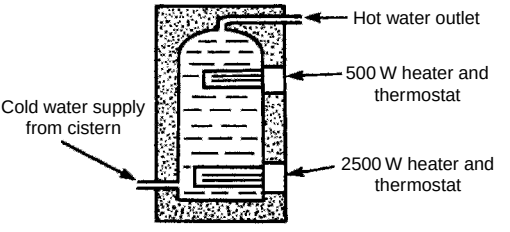
Cistern-type heater



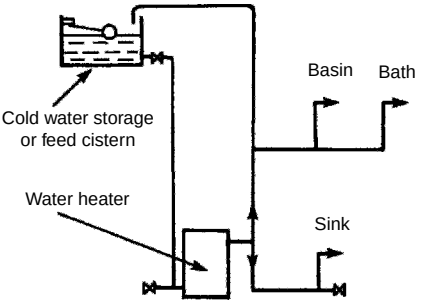
Installation of electric cistern-type heater

Ref. BS 3198: Specification for copper hot water storage combination units for domestic purposes.

The cistern-type heater should be located with the water level at least 1·5 m above the water draw-off taps. If there is insufficient space to accommodate this combination unit, a smaller pressure-type water heater may be fitted. These are small enough to locate under the sink or elsewhere in the kitchen. They have two immersion heaters, the upper element of 500 watts rating is for general use supplying hot water to the basin, sink and other small appliances. The lower element of 2500 watts may be on a timed control to provide sufficient hot water for baths. The pressure heater is supplied with cold water from a high level cistern.



Pressure-type electric water heater



Installation of pressure-type electric water heater

Immersion heaters – safety cut-out. Since 2004, immersion heater manufacturers are required to incorporate an additional integral safety device, independent of the main thermostat. This brings immersion heaters for vented water heating into line with the requirements for unvented water heaters.

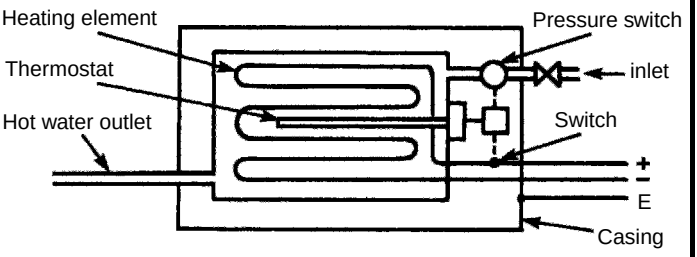
Function – if the main thermostat fails, water will boil, with considerable damage potential to personnel, the installation and premises. The manufacturer's pre-set safety cut-out is designed to prevent water in a hot water storage vessel exceeding 98°C. It must not re-set automatically.

Methods – either:

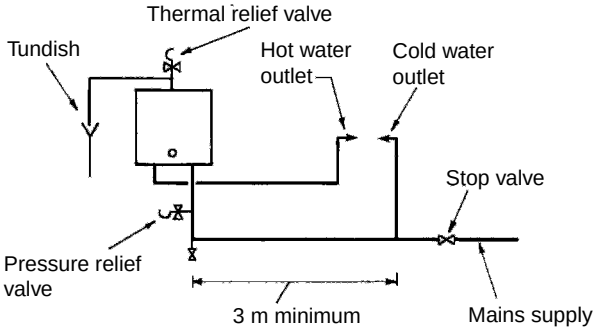
- A 'one-shot' thermal cut-out or thermostat. This is principally a fusible link which melts or ruptures at a pre-determined temperature, or
- A manually re-settable cut-out or thermostat which responds to critical temperature change to break electrical contact.

Ref. BS EN 60335-2-73: Specification for safety of household and similar electrical appliances. Particular requirements for fixed immersion heaters.

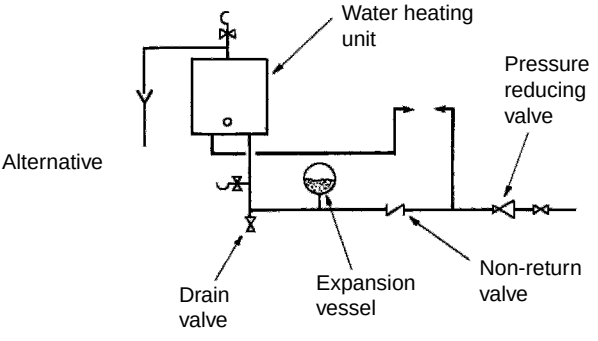
Instantaneous water heaters are relatively compact non-storage units suitable for use with individual sinks, basins and showers. For user safety they are fitted with a pressure switch to disconnect the electricity if the water supply is interrupted and a thermal cut-out to prevent the water overheating. Mains pressure to these units should be maintained below 400 kPa (4 bar). In some high pressure supply areas this will require a pressure reducing valve to be installed on the service pipe. Some expansion of hot water will occur whilst the unit is in use. This can be contained if there is at least 3 metres of pipework before the unit and the closest cold water draw-off. If this is impractical, an expansion vessel may be used. For more details of electric shower installations see pages 286 and 287.



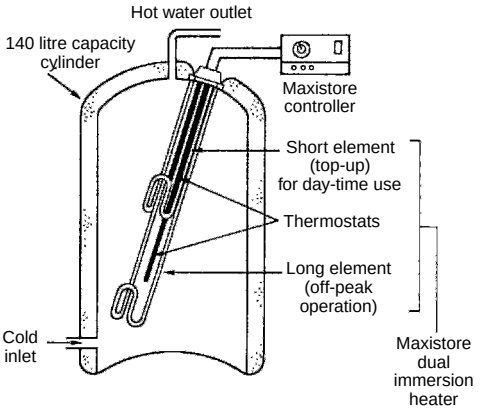
Instantaneous-type electric water heater



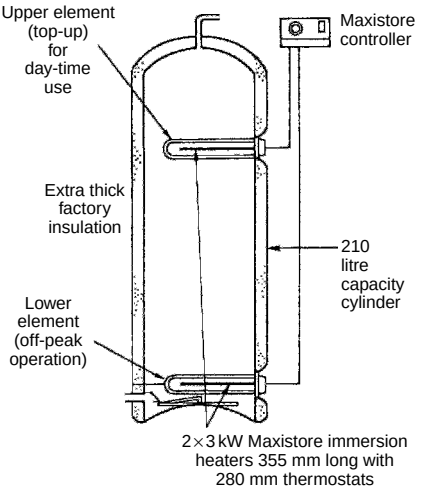
Installation of unvented hot water units of less than 15 litres capacity



Industrial, commercial and domestic demand for electricity is considerably reduced overnight. Therefore during this time, the electricity supply companies can market their spare capacity as off-peak electricity by selling it at a reduced rate – approximately half the cost of standard day time tariff. Supplies are adapted to operate through a programmer or time control which diverts the electricity to a special off-peak or white meter, usually from midnight to 7 a.m. In order to maximise the benefit, slightly larger than standard capacity hot water storage cylinders of 162 or 190 litres are recommended. To conserve energy, these cylinders must be thoroughly insulated and the immersion heaters fitted with integral thermostatic control. If supplementary hot water is required during the day, this can be provided by a secondary immersion heater at standard supply tariff.



Immersion heater for existing cylinder

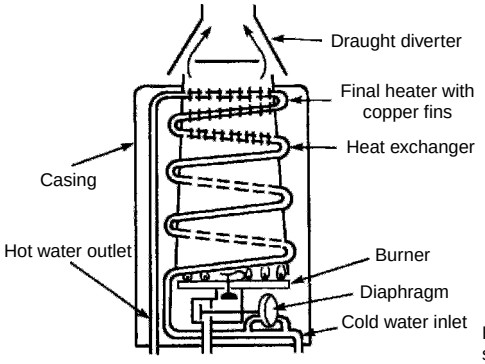


Special package unit

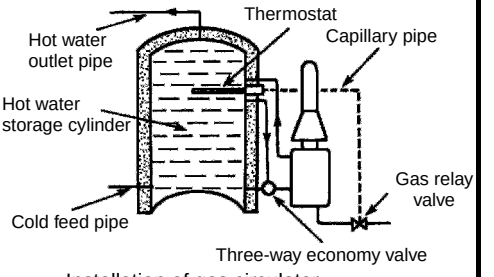
The secondary immersion heater or boost heater is close to the top of the cylinder to ensure that only a limited quantity of water is heated at standard tariff. To maximise economy, the off-peak thermostat is set at 65°C and the boost thermostat at 60°C.

When the hot water outlet is opened, cold water flows through a venturi fitting. The venturi contains a diaphragm which responds to the flow differential pressure and this opens the gas valve. A pilot flame ignites gas flowing through the burner which heats the water as it passes through the heat exchanger. Installation can be direct from the water main or from a cold water storage cistern. A multi-point system has the hot water outlet suppling several appliances.

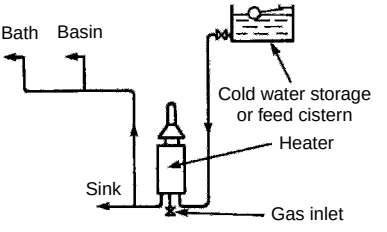
A gas circulator can be used to heat water in a storage cylinder. They are usually fitted with an economy or three-way valve. This gives optional use of water circulation through a high or low return pipe for variable hot water storage volume. Domestic installations may be in the kitchen, with vertical flow and return pipes to a storage cylinder in the airing cupboard.



Instantaneous gas water heater



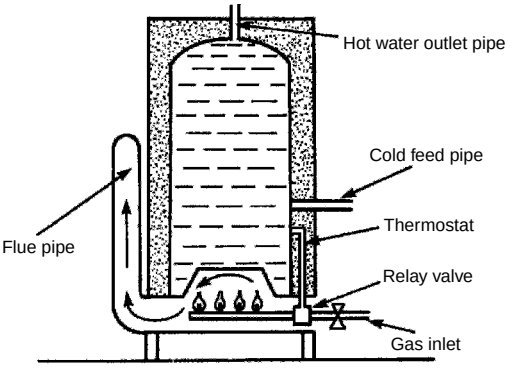
Installation of gas circulator



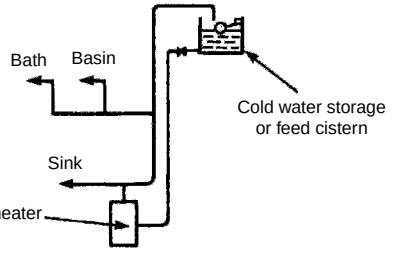
Installation of instantaneous gas water heater

Ref: BS EN 26: Gas fired instantaneous water heaters for the production of domestic hot water, fitted with atmospheric burners.

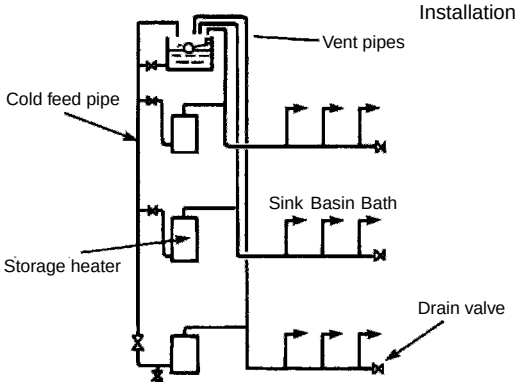
The storage type of gas water heater is a self-contained unit and is therefore simpler and quicker to install than a gas circulator. Capacities range from 75 to 285 litres. The smaller units are single-point heaters for supplying hot water to an individual sink or basin. Larger, higher rated storage heaters can be used to supply hot water to a bath, basin, sink and shower. These are called multi-point heaters. They may also be installed in flats up to three storeys, with cold water supplied from one cistern. A vent pipe on the cold feed will prevent siphonage. To prevent hot water from the heaters on the upper floors flowing down to the heater on the ground floor, the branch connection on the cold feed pipe must be above the heaters.



Detail of gas storage heater



Installation of gas storage heater for a house



Installation of gas storage heaters for three-storey flats
(electric pressure heaters may be similarly installed)

Condensing water heater – a variation on the multipoint type heater. The condensing heater is a hot water storage vessel, capable of very rapid heat recovery.

Application – typical examples include small hotels, schools, residential homes, student halls of residence, camp sites and sports centres.

Function – a fanned gas burner discharges into a stainless steel combustion chamber within a cylindrical water storage vessel. From the combustion chamber the burnt gases descend into a stainless steel spiral to exit at low level through a flue. Condensate from the flue is trapped and discharged to a drain.

Controls –

Automatic electric ignition in response to a water temperature thermostat.

Limit thermostat.

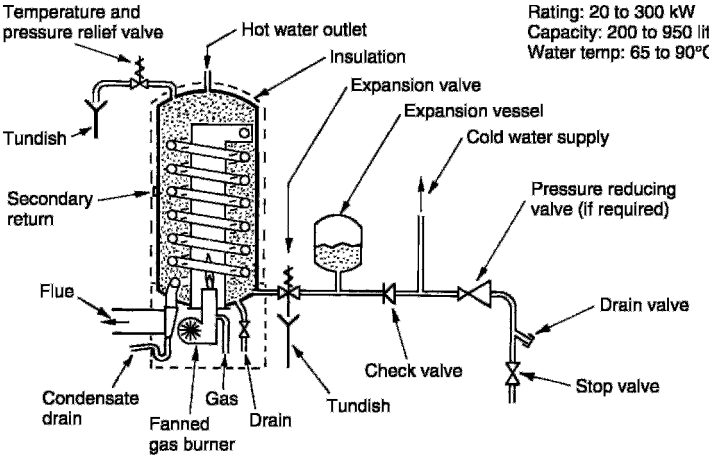
Overheat safety thermostat and warning light.

Fan failure device and warning light.

Manual on/off switch.

Water supply – either:

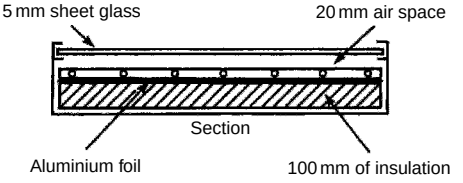
- Cistern, gravity feed pipe and atmospheric vent and expansion pipe, or
- Direct connection to an unvented mains supply. Unvented supplies require backflow prevention (check valve), an expansion vessel and an expansion valve. A pressure and temperature relief valve must also be fitted to the hot water outlet to discharge safely into a tundish.



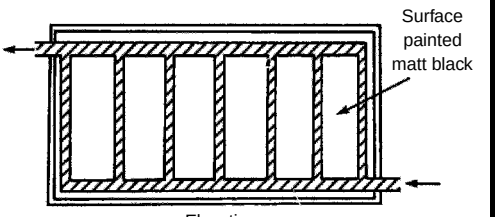
Mains connected condensing water heater

Solar Heating of Water

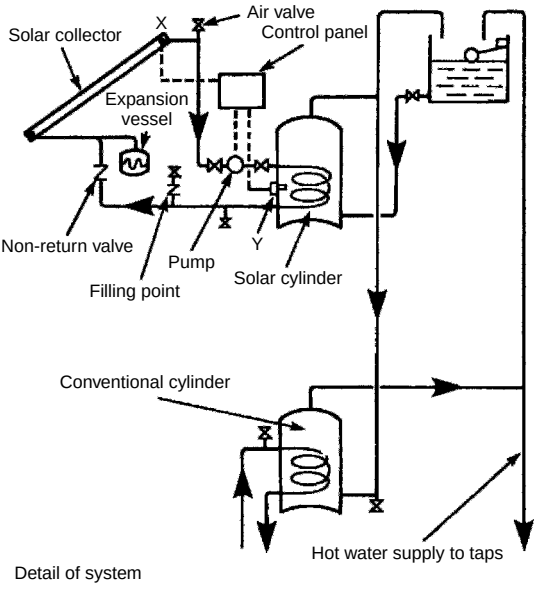
Solar energy can contribute significantly to hot water requirements. In some countries it is the sole source of energy for hot water. In the UK its efficiency varies with the fickle nature of the weather, but fuel savings of about 40% are possible. For domestic application, the collector should be 4 to 6 m^2 in area, secured at an angle of 40° to the horizontal and facing south. The solar cylinder capacity of about 200 litres is heated to 60°C. The cylinder and associated pipework must be very well insulated and the solar part of the system should contain a blend of water and non-toxic anti-freeze. The pump is switched on when the temperature of water at point X exceeds that at point Y by 2 to 3°C. The solar cylinder and the conventional cylinder may be fitted on the same level, or to save space a combined solar/conventional cylinder can be obtained from specialist suppliers.



Detail of flat plate solar collector



Elevation



Detail of system

The heat energy properties of water are fundamental for determining pipe sizes and component dimensions in hot water and heating systems.

HEAT is a form of energy, otherwise known as thermal energy. The standard unit of energy is the joule (J).

1 joule = amount of energy supplied by 1 watt (W) in 1 second (s).

Other units of energy found in older textbooks and product references include:

1 British thermal unit (1Btu) = 1·055 kJ
1 calorie (1 cal) = 4·187 J
1 kilowatt hour (1kWh) = 3·6 MJ
1 therm (1 therm) = 105·5 MJ

POWER is a measure of work rate.
Power (W) = heat energy (J) ÷ time in seconds (s)
Thus, 1W = 1 joule/second

TEMPERATURE is measured on a scale between two fixed points. These points are chosen at normal atmospheric pressure to represent water at the melting point of ice as zero, and the boiling point at 100, hence the term centigrade. A point on this scale is known as degrees Celcius (°C). The thermodynamic or absolute scale of temperature is represented in degrees Kelvin (K). Temperature intervals are the same as Celcius, but Kelvin originates at −273.15°C, the point at which no more internal energy can be extracted from a body. Temperature change intervals of 1°C and 1K are the same, except that:

thermodynamic temperature (K) = temperature in °C + 273.15

e.g. 1: water at 30°C = 303.15 K

e.g. 2: a hot water system with primary flow and return temperatures of 80°C and 70°C respectively, has a temperature differential of 10 K.

SPECIFIC HEAT CAPACITY (Shc) is the amount of heat energy required to raise 1 kilogram (kg) of a substance by 1K.

Some approximate values of Shc (will vary slightly with temperature and pressure):

Water	4180 J/kg K	Aluminium	910 J/kg K
Ice	2100	Cast iron	500
Nylon	1700	Copper/zinc	385
Air	1010	Lead	126

From the above, it can be seen that it would require over four times as much heat energy to raise 1kg of water 1K, than 1kg of air (4180 ÷ 1010 = 4.14). Conversely, as the Shc of water is relatively high, it is a good medium for storing heat. This is also a reason why hot water plant occupies less space than warm air systems, i.e. pipes are much smaller than air ducts conveying the same amount of energy.

Hot Water Storage Capacity

The capacity of hot water storage vessels must be adequate for the building purpose. Exact requirements are difficult to determine, but reasonable estimates are possible. These should include provision for rate of energy consumption (see table below) and the time taken to reheat the water to the required storage temperature (see boiler rating calculation – next page). Many buildings have variable use and inconsistent demands. This often creates an overdesign situation, unless care is taken to establish peak use periods and the system calculations adjusted accordingly. With these building types, non-storage instantaneous fittings may be preferred.

For most buildings the following table can be used as guidance:

Building purpose	Storage capacity (litres/person)	Energy consumption (kW/person)
Dwellings:		
single bath	30	0·75
multi-bath	45	1·00
Factory/Office	5	0·10
Hotels	35*	1·00
Hostels	30	0·70
Hospitals	35*	1·00
Schools/Colleges:		
day	5	0·10
boarding	25	0·70
Sports pavilions	35	1·00

* Average figures

E.g. A student hall of residence (hostel) to accommodate 50 persons.

Capacity: 50 × 30 = 1500 litres
Energy consumption: 50 × 0·70 = 35 kW

The nearest capacity storage vessel can be found from manufacturers' catalogues or by reference to BS 1566. For convenience, two or three cylinders of equivalent capacity may be selected.

Boilers are rated in kilowatts, where 1 watt equates to 1 joule of energy per second, i.e. W = J/s. Many manufacturers still use the imperial measure of British thermal units per hour for their boilers. For comparison purposes 1 kW equates to 3412 Btu/h.

Rating can be expressed in terms of gross or net heat input into the appliance. Values can be calculated by multiplying the fuel flow rate (m^3/s) by its calorific value (kJ/m^3 or kJ/kg). Input may be gross if the latent heat due to condensation of water is included in the heat transfer from the fuel. Where both values are provided in the appliance manufacturer's information, an approximate figure for boiler operating efficiency can be obtained, e.g. if a gas boiler has gross and net input values of 30 and 24 kW respectively, the efficiency is 24/30 × 100/1 = 80%.

Oil and solid fuel appliances are normally rated by the maximum declared energy output (kW), whereas gas appliances are rated by net heat input rate (kW[net]).

Calculation of boiler power:

$$kW = \frac{\text{kg of water} \times \text{S.h.c.} \times \text{Temp. rise}}{\text{Time in seconds}}$$

where: 1 litre of water weighs 1 kg
S.h.c. = specific heat capacity of water, 4·2 kJ/kgK
K = degrees Kelvin temperature interval
Temp. rise = rise in temperature that the boiler will need to increase the existing mixed water temperature (say 30°C) to the required storage temperature (say 60°C).
Time in seconds = time the boiler takes to achieve the temperature rise. 1 to 2 hours is typical, use 1·5 hours in this example.

From the example on the previous page, storage capacity is 1500 litres, i.e. 1500 kg of water. Therefore:

$$\text{Boiler power} = \frac{1500 \times 4{\cdot}2 \times (60 - 30)}{1{\cdot}5 \times 3600} = 35 \text{ kW net}$$

Given the boiler has an efficiency of 80%, it will be gross input rated:

$$35 \times 100/80 = 43{\cdot}75 \text{ kW}$$

Note: The boiler operating efficiency is the relationship between a unit of fuel energy consumed to produce a unit of heat energy in the appliance hot water. It is not to be compared with the seasonal efficiency of a boiler (SEDBUK), see page 72.

The water in primary flow and return pipework may circulate by convection. This produces a relatively slow rate of movement of about 0·2 m/s, depending on pipe length and location of boiler and cylinder. Modern systems are more efficient, incorporating a circulation pump to create a water velocity of between 0·75 and 3·0 m/s. This permits smaller pipe sizes and will provide a faster thermal response.

Inside diameter of pipe	Velocity min.	Velocity max. (copper)	Velocity max. (steel)
<50 mm	0·75 m/s	1·0 m/s	1·5 m/s
>50 mm	1·25 m/s	1·5 m/s	3·0 m/s

Exceeding these recommendations may lead to excessive system noise and possible pipe erosion.

E.g. using the Copper Development Association design chart shown on the next page, with the boiler rating from the previous example of 43.75 kW gross heat input and 35 kW net heat input.

$$\text{Mass flow rate (kg/s)} = \frac{\text{Boiler net heat input}}{\text{S.h.c.} \times \text{Temp. diff. (pf} - \text{pr)}}$$

Temperature difference between primary flow (pf) and primary return (pr) in pumped water circuits is usually about 10 K, i.e. 80°C–70°C. With convected circulation the return temperature will be about 60°C.

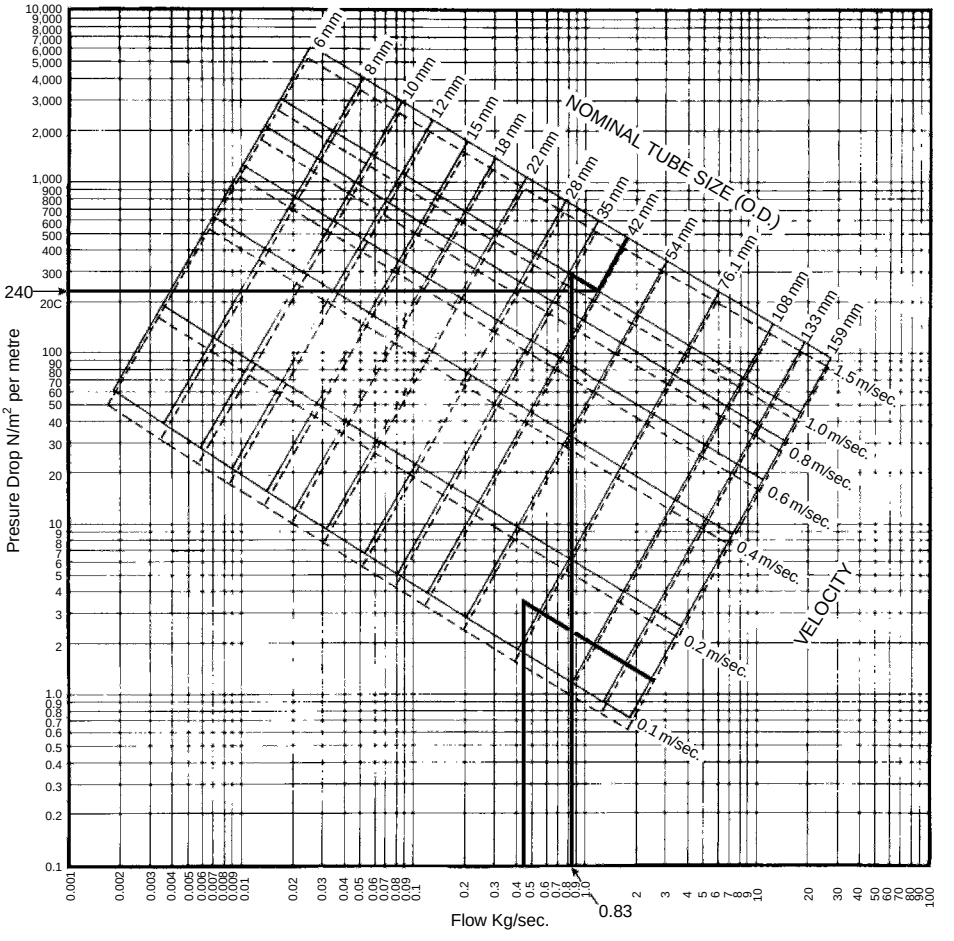
$$\text{Mass flow rate} = \frac{35}{4{\cdot}2 \times 10} = 0{\cdot}83 \text{ kg/s}$$

On the design chart, co-ordinating 0·83 kg/s with a pumped flow rate of 1 m/s indicates a 42 mm inside diameter copper tube. (35 mm is just too small.)

By comparison, using convected circulation of, say, 0·15 m/s and a mass flow rate with a 20 K temperature difference of 0·42 kg/s, the pipe size would be 76 mm.

Unpressurised hot water (approx. 65°C)

Pressurised hot water (approx. 115°C)



Reproduced with the kind permission of the Copper Development Association.

Circulation Pump Rating

Circulatory pumps produce minimal pressure in the primary flow and return, but the flow rate is considerably enhanced. The pressure can be ascertained from design charts as a pressure drop in N/m^2 per metre or pascals per metre. 1 N/m^2 equates to 1 pascal (Pa).

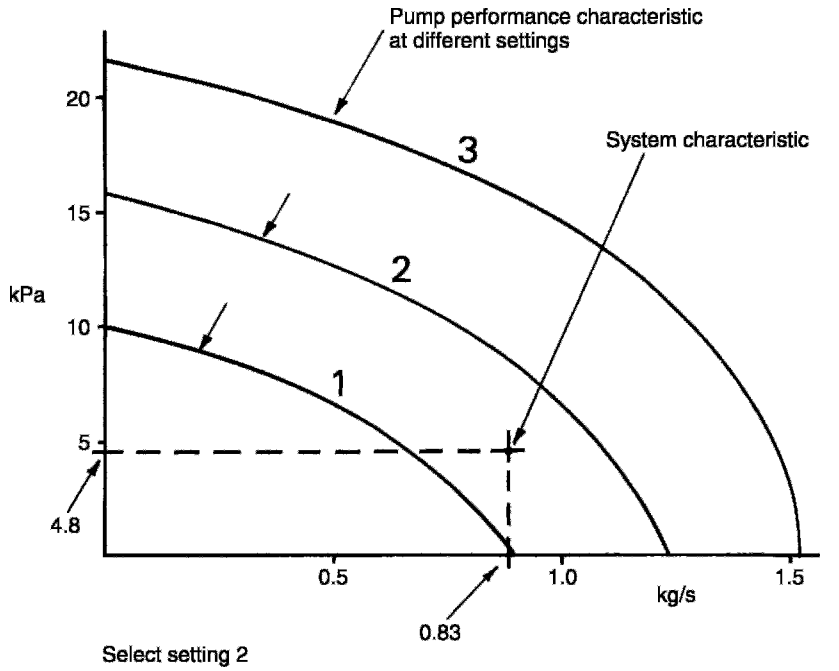
From the design chart, circulation in a 42 mm copper tube at 1 m/s produces a pressure drop of 240 Pa per metre. An estimate of the primary flow and return effective pipe length (see page 29) is required to establish the total resistance that the pump must overcome. For example, if the effective pipe length is 20 m:

240 × 20 = 4800 Pa or 4·8 kPa.

Therefore the pump specification would be 0·83 kg/s at 4·8 kPa.

Manufacturers' catalogues can be consulted to select a suitable pump. To provide for flexibility in installation, a degree of variable performance is incorporated into each model of pump. This range of characteristics can be applied by several different control settings as shown in the following graphic.

Pump performance chart:



Bacterial growths which cause Legionnaires' disease develop in warm, moist, natural conditions such as swamps. They have adapted to living in the built environment in the artificial atmosphere of air conditioning and hot water systems. A large number of outbreaks of the disease have occurred, with some people suffering a prolonged illness similar to pneumonia. The elderly are particularly vulnerable and many have died, hence the name of the illness which was attributed to a group of retired legionnaires who were infected whilst attending a reunion in Philadelphia, USA, in 1976. Numerous other outbreaks and subsequent deaths have led to strict maintenance and installation controls of services installations. This has been effected by the Health and Safety Executive under the Health and Safety at Work, etc. Act and the Workplace (Health, Safety and Welfare) Regulations. The following measures are recommended for use with hot water systems:

1. Stored hot water temperature 60 to 65°C throughout the storage vessel.

2. Routine maintenance involving heating the water to 70°C as a precaution.

3. Changing the design of cylinders and calorifiers with concave bases. These are suspect, as the lower recesses could provide areas of reduced water temperature with little or no movement.

4. Connections to storage vessels should encourage through movement of water.

5. Pipework `dead-legs' to be minimal.

6. All pipework to be insulated to reduce water temperature losses.

7. Where secondary circulation is required, supplementary trace element heating tape should be applied to maintain a minimum water temperature of 50°C.

8. Showers with recessed/concave outlet roses to be avoided. Other designs to have a self-draining facility to avoid inhalation of contaminated moisture droplets.

9. Spray taps – similar provision to 8.

Note: Cold water should be kept below 20°C.

SEDBUK is the acronym for *Seasonal Efficiency of Domestic Boilers in the United Kingdom*. It has developed under the Government's Energy Efficiency Best Practice Programme to provide a manufacturers' data base which represents the efficiency of gas- and oil-fired domestic boilers sold in the UK. See website: www.boilers.org.uk, or www.sedbuk.com. This voluntary site is updated monthly and it contains over 75% of new and existing products.

SEDBUK must not be confused with the operating efficiencies which are sometimes quoted in manufacturers' literature. These compare gross and net heat input values – see page 67. SEDBUK is the average annual in-use efficiency achieved in typical domestic conditions. The principal parameters included in the SEDBUK calculation are:

- type of boiler
- fuel ignition system
- internal store size
- type/grade of fuel.

Also included are the operating influences:

- typical patterns of usage – daily, weekly, etc.
- climatic variations.

Quoted SEDBUK figures are based on standard laboratory tests from manufacturers, certified by an independent Notified Body which is accredited for boiler testing to European Standards.

Efficiency bands:

Band	SEDBUK range (%)
A	>100
B	86–90
C	82–86
D	78–82
E	74–78
F	70–74
G	<70

See next page for the minimum acceptable band values for different fuel and installation types.

Building Regulations, Approved Document L1: Conservation of fuel and power in dwellings, required, from 2002, reasonable boiler efficiency for installations in new dwellings and for replacement equipment in existing dwellings. The following values applied:

Fuel system and boiler type	Min. SEDBUK value (%)
Natural gas	78
Natural gas back boiler	75
Liquid petroleum gas (LPG)	80
LPG back boiler	77
Oil	85
Oil combination boiler	82
Solid fuel	See HETAS certification

The SEDBUK database is an essential reference when calculating part of the Government's Standard Assessment Procedure for Energy Rating of Dwellings (SAP rating). Additional factors to be considered are: ventilation, heat losses through the fabric (U values) and solar gains. To comply with the Building Regulations, builders are required to submit energy rating calculations to the local building control authority. This data is also available for prospective house buyers and tenants for comparison purposes when assessing anticipated annual fuel costs for hot water and heating. SAP values vary from 1 to 120, with 80 considered the minimum expectation of new dwellings. SAP worksheets are available in the Appendices to Approved Document L1 of the Building Regulations.

Recognised organisations for accrediting `competent persons' as installers of domestic hot water and central heating systems:

Gas – Council for Registered Gas Installers (CORGI).

Oil – Oil Firing Technical Association for the Petroleum Industry (OFTEC).

Solid fuel – Heating Equipment Testing and Approval Scheme (HETAS).

Refs:

Building Regulations, Approved document L1 – Conservation of fuel and power in dwellings, 2002 and 2005.

The Government's Standard Assessment Procedure for Energy Rating of Dwellings, 2001 and 2005.

(Both published by The Stationery Office.)

The amended Building Regulations of 1990, 1995 and 2002 have made substantial improvements to standards of energy efficiency. Since 2002, several more initiatives have been applied to the installation and use of fuel-consuming appliances and attention to details of construction. Buildings have been specifically identified as the source of about 50% of all atmospheric carbon emissions. Half of this is attributed to emissions from domestic hot water and heating equipment.

The initial objectives are to:

- Reduce the carbon dioxide (CO_2) emissions from boilers by some 60% by around 2050. Real progress to be achieved by 2020.
- Maintain the reliability of fuel energy supplies and resources.
- Promote a competitive energy market in order to encourage sustainable economic growth and productivity.
- Ensure that all homes are adequately and affordably heated.

Effects:

- Domestic boilers – new and replacement appliances of SEDBUK rating A or B only, i.e. high efficiency condensing boilers.
- Insulation standards for new and refurbished buildings improved, e.g. replacement windows and reduced 'U' values.
- Regular inspection and maintenance of air conditioning systems.
- Measures to prevent overheating by solar gain.
- Installation of energy recovery systems, e.g. MVHR and heat pumps.
- Restricted use of inefficient appliances, e.g. gas decorative effect fires.
- Insulation of hot and chilled water pipework and sealing of ductwork joints to prevent air leakage.
- Use of high efficacy electric lamps and power rating limitations on external lighting.
- Calculation of carbon emission limits from dwellings, re. SAP ratings. For other buildings measures required to show improvements, such as renewable energy use, solar systems and CHP.
- Reduced air leakage through the building envelope, max. 10 m^3/hour/m^2.

Government energy policy:

- Reduced oil, gas and coal production.
- Deep mined coal resources exhausted by 2015.
- Coal fired power stations to be phased out.
- Nuclear power stations to be phased out.
- Net importer of gas by 2006.
- Net importer of oil by 2010.
- By 2020, expected that 75% of UK prime energy supplies will be imported.
- Low carbon economy – reduced greenhouse gases.
- Microcombined heat and power (CHP) units to be encouraged. Fuel cells and other renewable energy sources to be developed.

Refs.

Government White Paper: Our Energy Future – Creating a Low Carbon Economy. Published 2003 by the DTI.

Building Regulations, Approved Document L: Conservation of fuel and power, 2005.

Electrolysis – the corrosion or decomposition of different metals in the presence of water. Three criteria exist which will encourage corrosion:

- Neutral or acidic water, pH value ⩽7
- Warm or hot water
- Metals widely apart on the electrochemical or galvanic series.

Electrochemical series for metals used in plumbing and hot water services:

Protected end (cathode)	Stainless steel
	Copper
	Gunmetal and bronze
	Tin
	Lead
	Steel
	Cast iron
	Aluminium
	Zinc (galvanising)
Corroded end (anode)	Magnesium

Water functions as an electrolyte, i.e. a solution which conducts an electric current between a cathode and anode of dissimilar metals. Therefore, in water services systems materials must be compatible, otherwise decomposition of pipework and equipment will occur. For example, galvanised steel and copper pipes should never be used together, particularly in hot water installations.

Plumbo-solvency – term used to describe the breakdown of lead pipes conveying water with `soft´ characteristics. This should not be a problem, as for health reasons lead is no longer acceptable as a water services material. However, exposed lead flashings could be affected in areas of `soft´ rainwater.

Cupro-solvency – term used to describe the breakdown of copper pipes where soft water contains dissolved carbon dioxide. This type of water is generally associated with private wells and springs.

Dezincification – this affects brass pipe fittings and valves. Brass is an alloy of copper and zinc (50:50). Electrolytic reaction between the two metals, particularly in high chloride waters, causes corrosion of the zinc. This leaves the fitting unchanged in appearance, but with no strength and possibly porous. Installations in areas known to be prone to this problem should be specified with gunmetal fittings, an alloy of copper, tin and zinc (85:10:5).

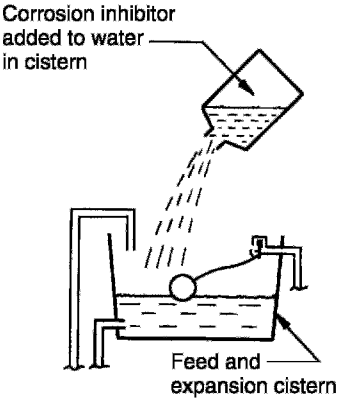
Anodic protection – before the introduction of plastic storage cisterns it was common practice to fit a sacrificial anode of magnesium into galvanised cold water storage cisterns if copper pipes were used. As magnesium is below zinc in the electrochemical series, the magnesium dissolved away instead of the galvanising. Sacrificial anodes are fitted as a precautionary measure to the inside of copper hot water storage cylinders.

Bacteria – the most common bacteria in water systems is *Pseudomonas* bacteria. It occurs where there is lack of water circulation or stagnation in discontinuous lengths of pipes and storage vessels. The latter is typical of expansion and feed cisterns in indirect hot water and central heating systems. High ambient temperatures between 20 and 40°C and poorly ventilated roof spaces or compartments are ideal for its development. First indications are usually its highly putrid odour. Inspection usually reveals a brown slimy film lining the water surface and storage cistern. Eradication is by flushing and disinfection with biocides in solution.

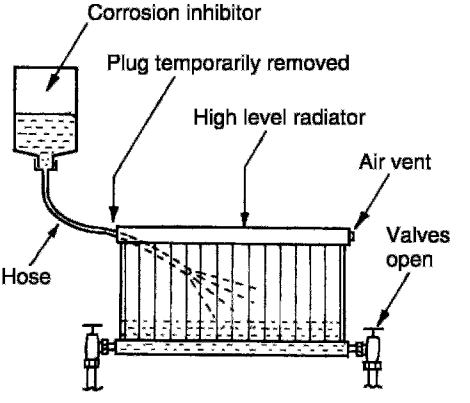
Corrosion Inhibitors – see also page 134. Boiler and associated equipment will only operate effectively and efficiently if water in the system is maintained clean and free of impurities. The minimal build up of scale or magnetite sludge will significantly reduce boiler efficiency and increase its contribution to carbon emissions.

New systems should be flushed to remove debris such as metal filings, flux and loose solder deposits. Filling is with clean water and the manufacturer's recommended dose of corrosion inhibitor, as shown in the illustrations. Following maintenance, repair or modification, existing systems should be treated similarly.

Proprietary corrosion inhibitors may be compounds of sodium silicate, benzoate, nitrite and chromate. Sodium pentachlorophenate is a bacteriacide or biocide which can be used to prevent the accumulation of hydrogen gas in radiators.

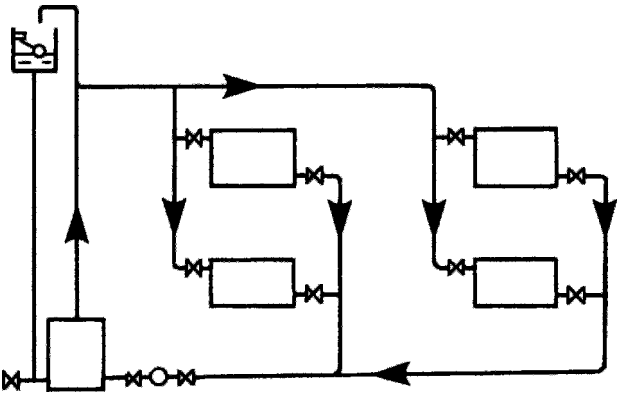


Dosing an open vent system



Dosing a sealed system

3 HEATING SYSTEMS

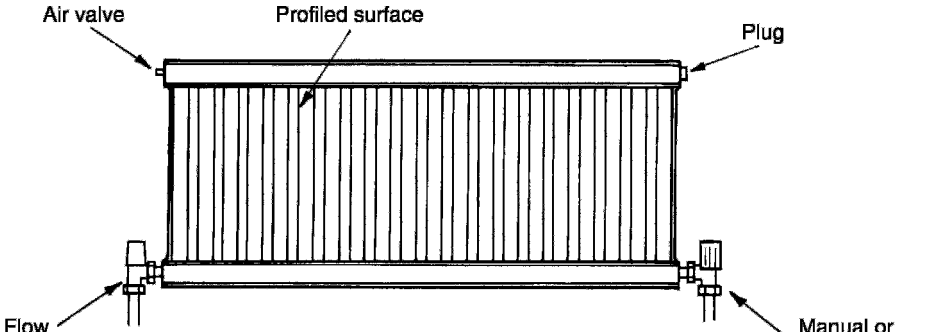


HEAT EMITTERS
LOW TEMPERATURE, HOT WATER HEATING SYSTEMS
UNDERFLOOR AND PANEL HEATING
EXPANSION FACILITIES IN HEATING SYSTEMS
EXPANSION VESSELS
SOLAR SPACE HEATING
HIGH TEMP., PRESSURISED HOT WATER SYSTEMS
STEAM HEATING SYSTEMS
DISTRICT HEATING
COMBINED HEAT AND POWER
EXPANSION OF PIPEWORK
THERMOSTATIC CONTROL OF HEATING SYSTEMS
TIMED CONTROL OF HEATING SYSTEMS
ZONED CONTROLS
ENERGY MANAGEMENT SYSTEMS
AUTOMATIC BYPASS CONTROL
FROST PROTECTION
WIRELESS HEATING CONTROLS
WARM AIR HEATING SYSTEM
HEATING DESIGN
'U' VALUES

Radiators and convectors are the principal means of heat emission in most buildings. Less popular alternatives include exposed pipes and radiant panels for use in warehousing, workshops and factories, where appearance is not important. Embedded panels of pipework in the floor screed can also be used to create 'invisible' heating, but these have a slow thermal response as heat energy is absorbed by the floor structure.

Despite the name radiator, no more than 40% of the heat transferred is by radiation. The remainder is convected, with a small amount conducted through the radiator brackets into the wall. Originally, radiators were made from cast iron in three forms: hospital, column and panel. Hospital radiators were so called because of their smooth, easy to clean surface, an important specification in a hygienic environment. Column radiators vary in the number of columns. The greater the number, the greater the heat emitting surface. Cast iron radiators are still produced to special order, but replicas in cast aluminium can be obtained. Cast iron panels have been superseded by pressed profiled steel welded panels. These are much slimmer and easier to accommodate than cast iron in the modern house. In addition to the corrugated profile, finned backing will also increase the heating surface and contribute to a higher convected output. Pressed steel radiators are made in single, double and triple panels.

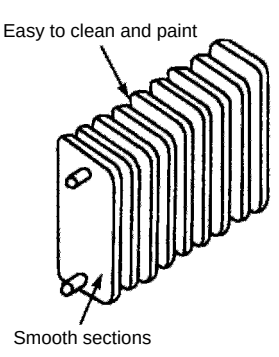
Convectors have a steel casing containing a finned heat exchanger. About 90% of the heat emission is convected and this may be enhanced if a thermostatically controlled fan is also located in the casing. They are more effective than radiators for heating large rooms, and in this situation their extra bulk can be accommodated.



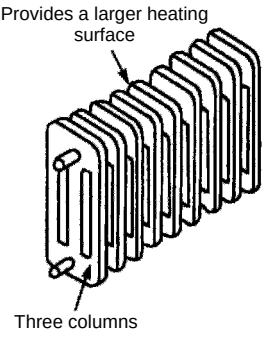
Pressed steel radiator and connections

In temperate and cold climates where there is insufficient warmth from the sun during parts of the year, heat losses from the human body must be balanced. These amount to the following approximate proportions: radiation 45%, convection 30% and evaporation 25%. Internal heat gains from machinery, lighting and people can contribute significantly, but heat emitters will provide the main contribution in most buildings.

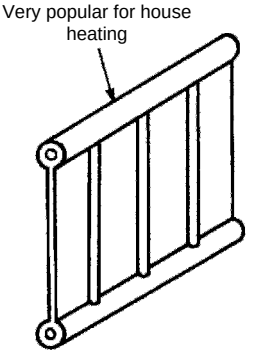
Enhancement of radiator performance can be achieved by placing a sheet of reflective foil on the wall between the fixing brackets. Emitter location is traditionally below window openings, as in older buildings the draughts were warmed as they infiltrated the ill-fitting sashes. With quality double glazed units this is no longer so important and in the absence of a window, locating a shelf above the radiator will prevent pattern staining of the wall due to convective currents. Radiant panels and strips suspend from the ceiling in industrial premises and other situations where wall space is unavailable.



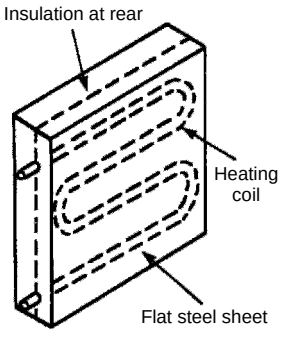
Hospital-type radiator



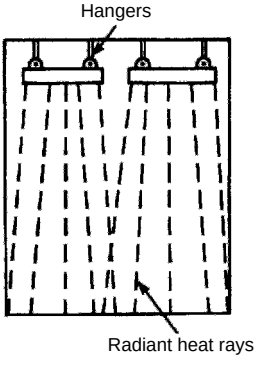
Column-type radiator



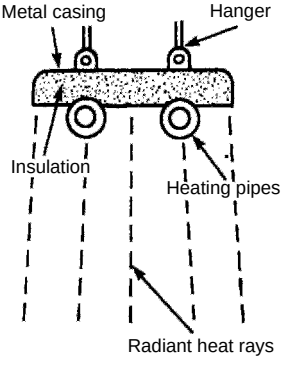
Panel-type radiator



Radiant panel

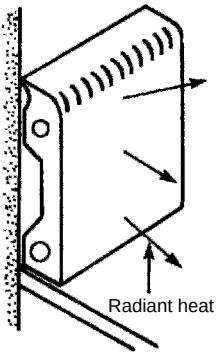


Radiant panels fixed overhead

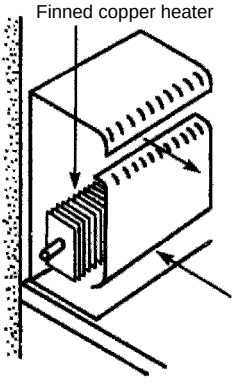


Radiant strip

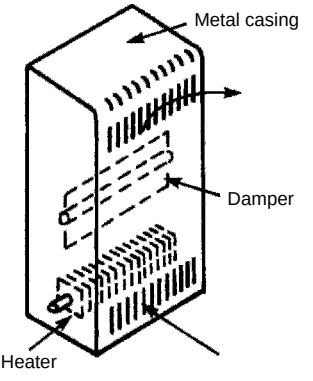
Radiant and convector skirting heaters are unobtrusive at skirting level and provide uniform heat distribution throughout a room. Natural convectors have a heating element at a low level within the casing. This ensures that a contained column of warm air gains velocity before discharging to displace the cooler air in the room. Fan convectors may have the heater at high level with a variable speed fan located below. In summer, the fan may also be used to create air circulation. Overhead unit heaters are used in workshops to free the wall space for benches, machinery, etc. A variation may be used as a warm air curtain across doorways and shop entrances. Individual unit heaters may have a thermostatically controlled inlet valve or a bank of several units may be controlled with zoning and diverter valves to regulate output in variable occupancy situations.



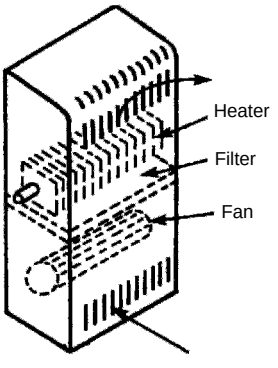
Radiant skirting heater



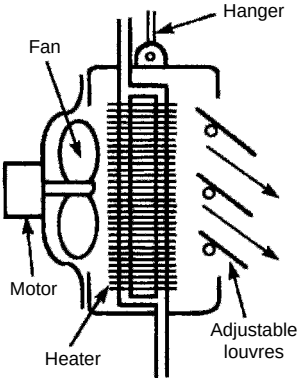
Convector skirting heater



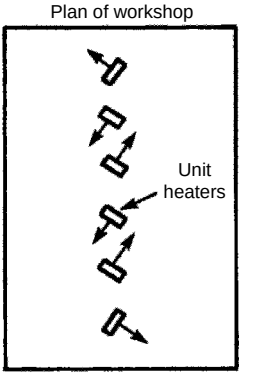
Natural convector



Fan convector



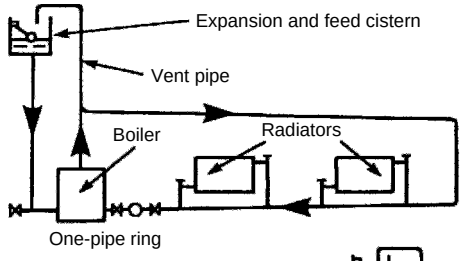
Overhead unit heater

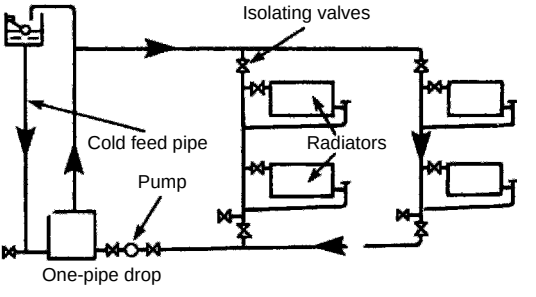


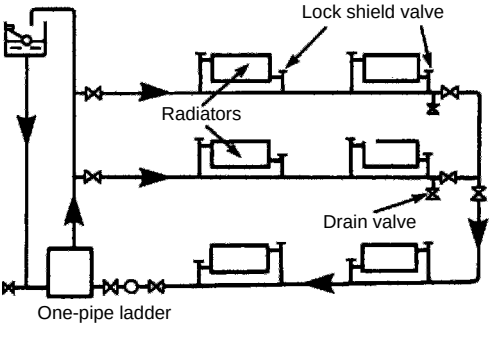
Method of siting overhead unit heaters

In low temperature, hot water heating systems the boiler water temperature is thermostatically controlled to about 80°C. Systems may be `open' with a small feed and expansion cistern or mains fed `sealed' with an expansion vessel.

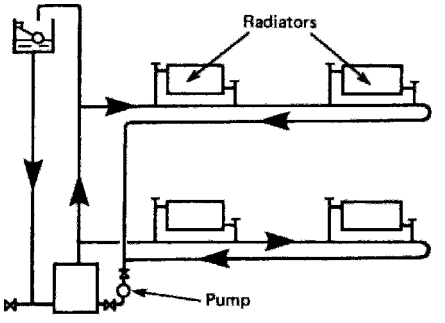
The type of system and pipe layout will depend on the building purpose and space available for pipework. A ring or loop circuit is used for single-storey buildings. Drop and ladder systems are used for buildings of several storeys. The drop system has the advantage of being self-venting and the radiators will not become air locked. Traditional solid fuelled systems operate by convection or gravity circulation (otherwise known as thermo-siphonage). Contemporary practice is to install a pump for faster circulation and a more rapid and effective thermal response. This will also complement modern fuel controls on the boiler and allow for smaller pipe sizes. The additional running costs are minimal.



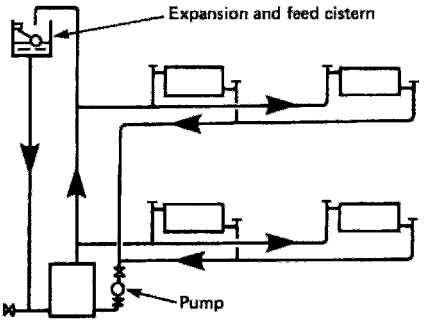




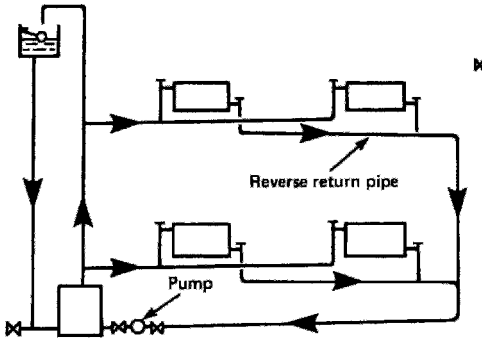
The one- and two-pipe parallel systems are useful where pipework can be accommodated within a floor structure, a raised floor or a suspended ceiling. The disadvantage with all one-pipe systems is the difficulty of supplying hot water to the radiators furthest from the boiler. As the heat is emitted from each radiator, cooling water returns to mix with the hot water supplying subsequent radiators, gradually lowering the temperature around the circuit. Eventually the last or 'index' radiator receives lukewarm water at best, necessitating a very large radiator to provide any effect. Pumped circulation may help, but it will require a relatively large diameter pipe to retain sufficient hot water to reach the 'index' radiators. Two-pipe systems are less affected, as the cool water from each radiator returns directly to the boiler for reheating. However, radiators will need flow balancing or regulating to ensure an even distribution of hot water. The reverse-return or equal travel system requires the least regulating, as the length of pipework to and from each radiator at each floor level is equal. In all systems the circulating pump is normally fitted as close to the boiler as possible, either on the heating flow or return. Most pump manufacturers recommend location on the higher temperature flow.



One-pipe parallel

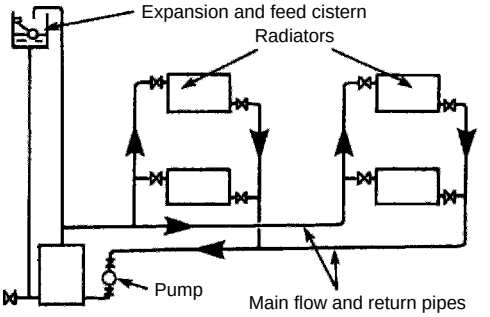


Two-pipe parallel

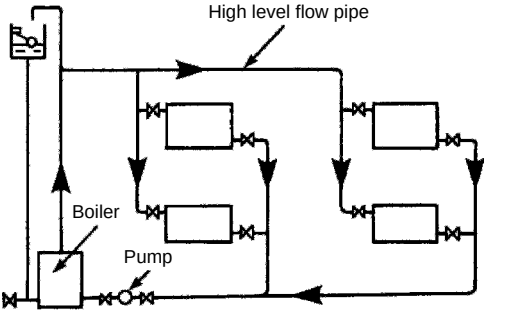


Two-pipe reverse return

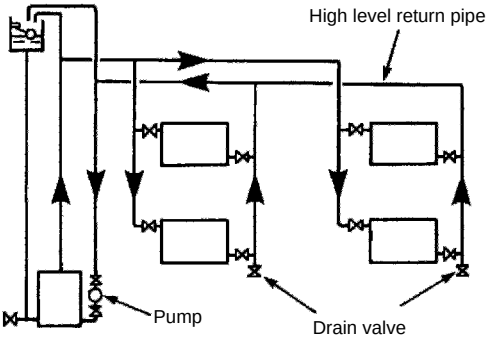
The two-pipe upfeed system is used when it is impractical to locate pipes horizontally at high level. The main heating distribution pipes can be placed in a floor duct or within a raised floor. The two-pipe drop is used where a high level horizontal flow pipe can be positioned in a roof space or in a suspended ceiling, and a low level return within a ground floor or basement ceiling. This system has the advantage of self-venting. The two-pipe high level return system is particularly appropriate for installation in refurbishments to existing buildings with solid ground floors. In this situation it is usually too time consuming, impractical and possibly structurally damaging to cut a trough or duct in the concrete.



Two-pipe upfeed



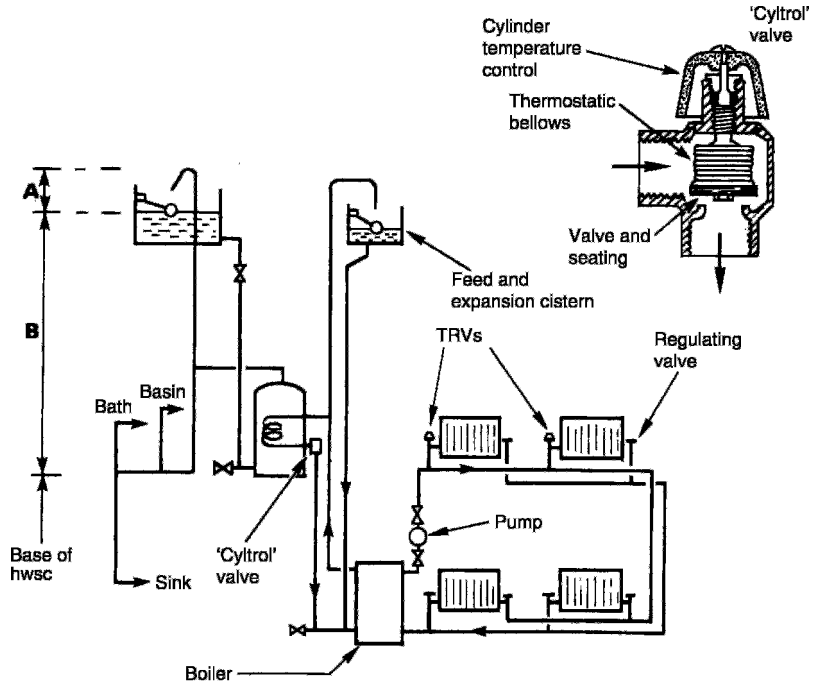
Two-pipe drop



Two-pipe high level return

Low Temperature, Small Bore Hot Water Heating System

Pumped small bore heating systems have 28 or 22 mm outside diameter copper tube for the main heating flow and return pipework, with 15 mm o.d. branches to each radiator. This compares favourably with the old gravity/convection circulation systems which sometimes required pipes of over 50 mm diameter to effect circulation. If cylinder and boiler are separated vertically by floor levels, there will be sufficient pressure for hot water to circulate by convection through the primary flow and return pipes. However, most modern systems combine a pumped primary and heating flow with circulation regulated by thermostats and motorised valves. Variations in one and two pipe systems are shown on pages 81–83. Two pipe systems are always preferred for more effective hot water distribution.



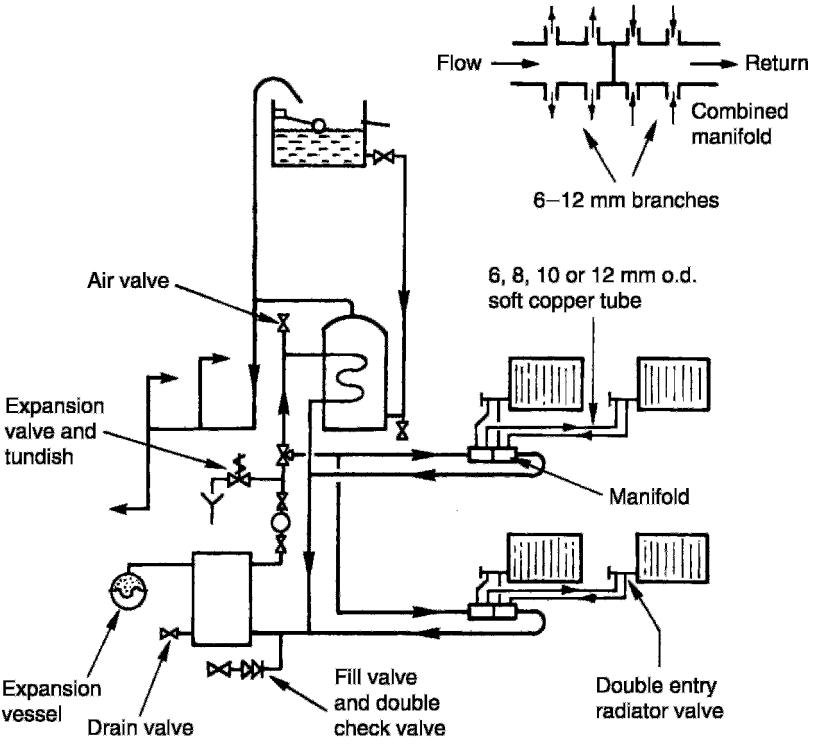
Small bore heating system

Notes:

1. `Cyltrol´ valve to be as close as possible to hwsc, to sense hot water return temperature and maintain stored water at about 55°C. Where used with a solid fuel boiler, an unvalved radiator or towel rail is connected across the primary pipes to dissipate excess heat when the `cyltrol´ closes.

2. Min. height of expansion pipe above cistern water level (A) = (B) in metres × 40 mm + 150 mm. E.g. if (B), cistern water level to base of hwsc is 2·5 m, then (A) is 2·5 × 40 mm + 150 mm = 250 mm.

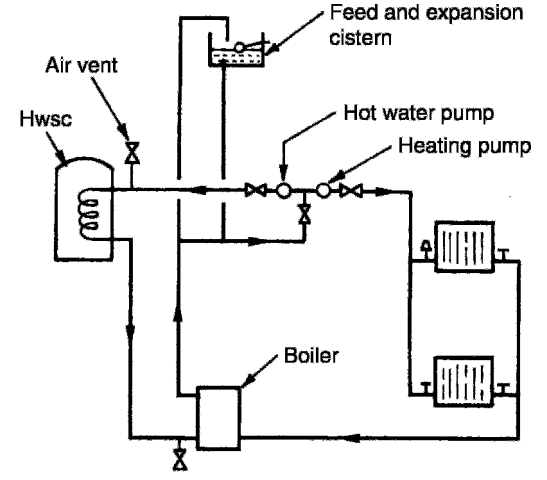
The microbore system also has pumped circulation through 28 or 22 mm o.d. copper tube main flow and return pipes to radiators. The diameter depending on the number and rating of emitters connected. The difference between this system and conventional small bore is the application of a centrally located manifold between boiler and emitters. Manifolds are produced with standard tube connections for the flow and return and several branches of 6, 8, 10 or 12 mm outside diameter. A combined manifold is also available. This is more compact, having a blank in the middle to separate flow from return. Manifolds are generally allocated at one per floor. Systems may be open vented or fitted with an expansion vessel. The advantage of microbore is ease and speed of installation, as long lengths of small diameter soft copper tubing are produced in coils. It is also unobtrusive where exposed, very easily concealed and is less damaging to the structure when holes are required. Water circulation noise may be noticeable as velocity is greater than in small bore systems. Pumped circulation is essential due to the high resistance to water flow in the small diameter pipes.



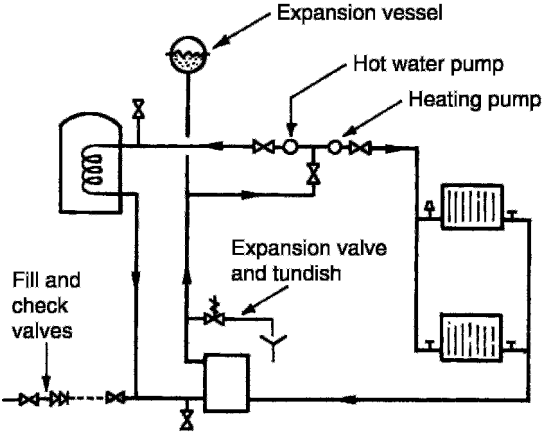
Microbore system

Double Pump Heating and Hot Water Control

This is an alternative method for distributing hot water. It can be effected by using two separate pumps from the boiler flow: one to supply the hot water storage cylinder and the other the heating circuit. Grundfos Pumps Ltd. have developed a purpose-made dual pump for this purpose, which is integrated into one body. This system conveniently replaces the conventional single pump and associated two or three port motorised distribution valves. Each pump is dedicated to hot water or heating and individually controlled by cylinder or room thermostat. The correct flow and pressure can be regulated to the characteristics of the specific circuit.

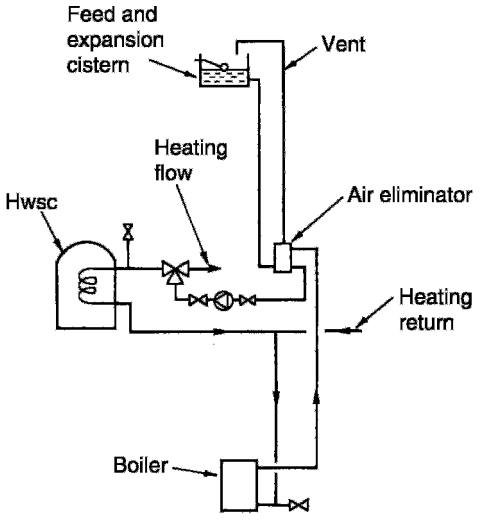


Conventional open vent system

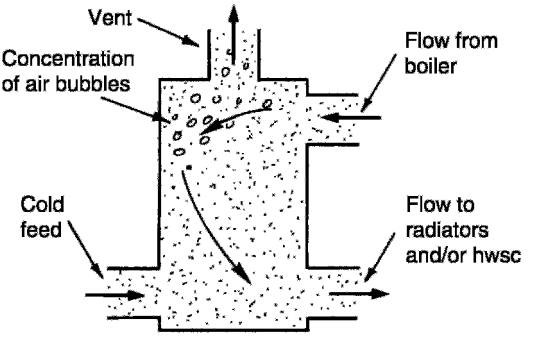


Typical sealed system

In conventional low pressure systems, air and other gases produced by heating water should escape through the vent and expansion pipe. Air must be removed to prevent the possibility of air locks, corrosion and noise. To assist air removal, a purpose-made device resembling a small canister may be used to concentrate the gases. This simple fitting is located on the boiler flow and vent pipe to contain the water velocity and ensure efficient concentration and release of air into the vent.



Application of air eliminator

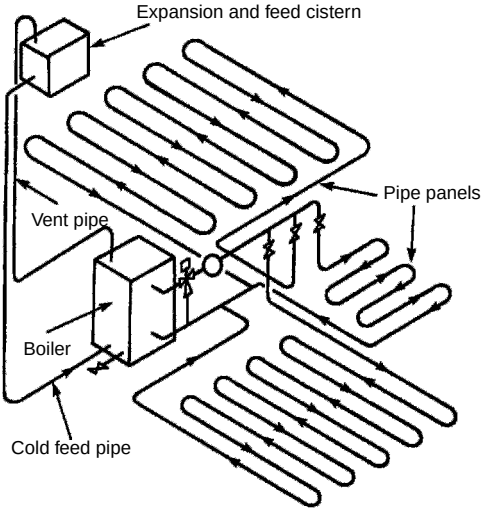


Air eliminator (approx. 100 mm high × 75 mm dia. with standard 22 mm o.d. copper tube connections)

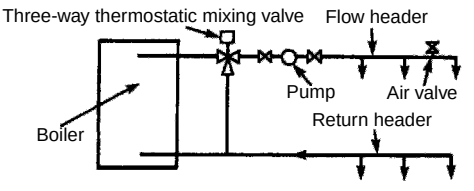
The system consists of 15 mm or 22 mm o.d. annealed copper pipes embedded in the floor, ceiling or walls. This has the benefit of avoiding unsightly pipes and radiators. Heat distribution is uniform, providing a high standard of thermal comfort as heat is emitted from the building fabric. However, thermal response is slow as the fabric takes time to heat up and to lose its heat. Thermostatic control is used to maintain the following surface temperatures:

Floors – 27°C
Ceilings – 49°C
Walls – 43°C

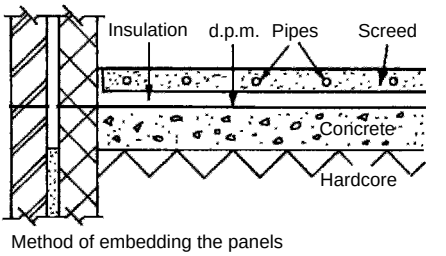
Joints on copper pipes must be made by capillary soldered fittings or by bronze welding. Unjointed purpose-made plastic pipes can also be used. Before embedding the pipes they should be hydraulically tested as described on page 133.



Installation of panel heating system



Detail of boiler and connections



Method of embedding the panels

Current practice is to use jointless plastic pipe in continuous coils. Pipes can be embedded in a 70 mm cement and sand screed (50 mm minimum cover to tube). In suspended timber floors the pipe may be elevated by clipping tracks or brackets with metallic reflective support trays, prior to fixing the chipboard decking. Materials include:

PEX: Cross linked polyethylene.

PP: Co-polymer of polypropylene.

PB: Polybutylene.

These pipes are oxygen permeable, therefore, when specified for underfloor heating, they should include a diffusion barrier.

Boiler flow temperature for underfloor heating is about 50°C, whilst that for hot water storage and radiators is about 80°C. Therefore, where the same boiler supplies both hot water storage cylinder and/or radiators and underfloor heating, a motorised thermostatic mixing valve is required to blend the boiler flow and underfloor heating return water to obtain the optimum flow temperature.

Extract from performance tables for a design room temperature of 21°C with a blended flow temperature of 50°C:

Solid floor – Pipe dia. (mm)	Pipe spacing (mm)	Output (W/m^2)
15	100	82
15	200	67
18	300	55
Suspended floor –		
15	300*	47

*Assumes two pipe runs between floor joists spaced at 600 mm centres.

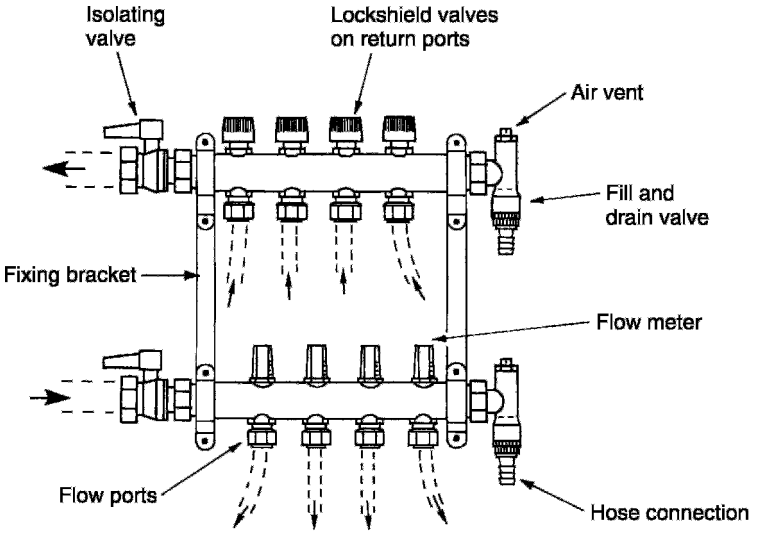
For a room with a solid floor area of 13·5 m^2 requiring a heating input of 779 watts (see page 125), the output required from the underfloor piping is:

$$779 \div 13{\cdot}5 = 57{\cdot}7 \text{ watts}/m^2$$

Therefore, 15 mm diameter pipe at 200 mm spacing (67 W/m^2) is more than adequate, whilst 18 mm diameter pipe at 300 mm spacing (55 W/m^2) is just below.

Manifold or header – manifolds are discretely located on a wall or within a boxed unit. Manifolds comprise:-

- Flow ports (2–12).
- Return ports (2–12).
- Drain valve and hose connection (may be used for filling).
- Air ventilation valve.
- Isolating valve to each bank of ports.
- Visual flow meters to each flow port.
- Lockshield balancing valve on each return port.



Underfloor heating manifold

Installation notes –

- One circulator per manifold.
- Combined radiator and panel systems, one circulator for each system.
- Screeded floor to have insulation turned up at edge to provide for expansion. Max. 40 m^2 or 8 m linear, without expansion joint.
- Timber floor to have 6–8 mm expansion gap around periphery.

Refs.

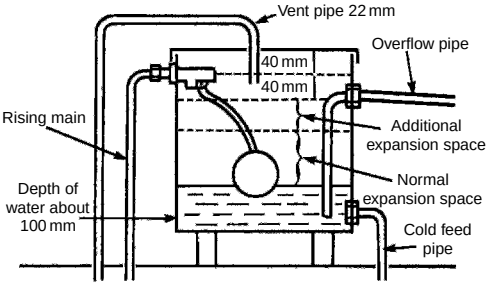
BS 5955-8: Plastics pipework.

BS 7291-1 and 2: Thermoplastic pipes.

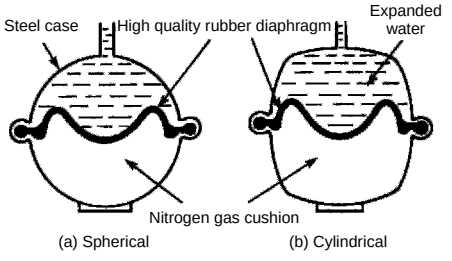
BS EN 1264-4: Floor heating. Systems and components. Installation.

In any water heating system, provision must be made for the expansion of water. A combined expansion and feed cistern is the traditional means. This will have normal expansion space under usual boiler firing conditions of about 4% of the total volume of water in the system, plus a further third as additional expansion space for high boiler firing. Although the expansion can be accommodated up to the overflow level, there should be at least 25 mm between overflow and the fully expanded water level.

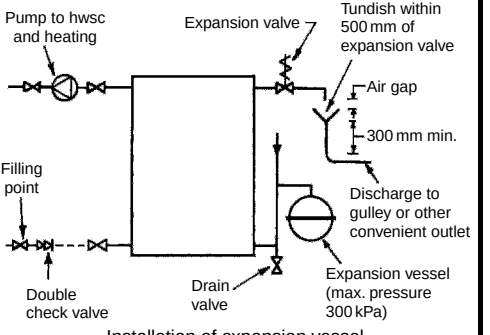
Contemporary sealed systems have an expansion vessel connected close to the boiler. It contains a diaphragm and a volume of air or nitrogen to absorb the expansion. To conserve wear on the diaphragm, location is preferred on the cooler return pipe and on the negative side of the pump. System installation is simpler and quicker than with an expansion cistern. The air or nitrogen is pressurised to produce a minimum water pressure at the highest point on the heating system of 10 kPa (approx. 1 m head of water). This is necessary, otherwise when filling the system, water would fill the vessel leaving no space for expansion.



Expansion and feed cistern



Diaphragm expansion vessels



Installation of expansion vessel

Expansion Vessels

Expansion vessels are produced to BS 6144. They must be correctly sized to accommodate the expansion of heated water without the system safety/pressure relief valve operating. The capacity of an expansion vessel will depend on the static pressure (metres head from the top of the system to the expansion vessel), the system maximum working pressure (same setting as p.r.v.) obtained from manufacturer's details and the volume of water in the system (approx. 15 litres per kW of boiler power).

Capacity can be calculated from the following formula:

$$V = \frac{e \times C}{1 - P_i/P_f}$$

where: V = vessel size (litres)
e = expansion factor (see table)
C = capacity of system (litres)
P_i = static pressure (absolute)*
P_f = max. working pressure (absolute)*

* absolute pressure is 1 atmosphere (atm) of approx. 100 kPa, plus system pressure.

E.g. C = 100 litres
P_i = 1·5 atm or 150 kPa (5 m head static pressure)
P_f = 1·9 atm or 190 kPa (9 m head static pressure)

Water temp. = 80°C

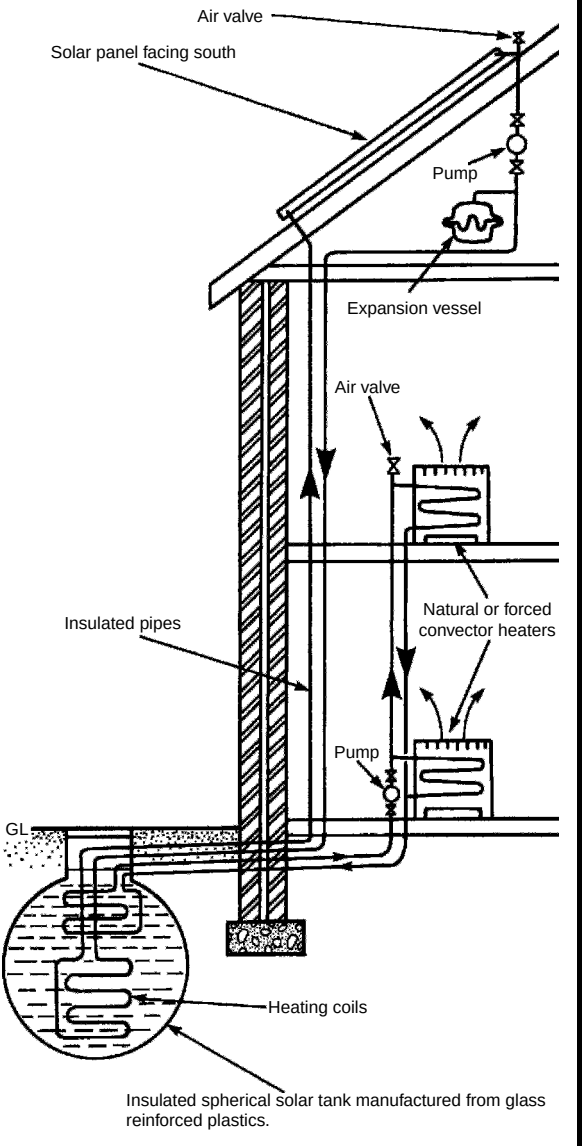
Temp. °C	Exp. factor
50	0·0121
60	0·0171
70	0·0227
80	0·0290
90	0·0359

$$V = \frac{0{\cdot}029 \times 100}{1 - 150/190} = 13{\cdot}80 \text{ litres}$$

Ref: BS 6144, Specification for expansion vessels using an internal diaphragm, for unvented hot water supply systems.

Solar space heating must be complemented with a very high standard of thermal insulation to the building fabric. The solar panel shown on page 64 for hot water provision will need a much larger area, typically 40 m^2 for a 3 to 4 bedroom detached estate house. A solar tank heat exchanger of about 40 m^3 water capacity is located in the ground. It is fitted with a pre-set safety type valve which opens to discharge water to waste if it should overheat. The solar panel and associated pipework are mains filled and supplemented with a glycol or anti-freeze additive.

With diminishing fossil fuel resources and inevitable rising fuel prices, solar heating is encouraged as a supplement or even an alternative to conventionally fuelled systems. For use as the sole energy for a heating system there is still considerable scope for research and development. Technological developments are improving, particularly with the 'heat bank' or storage facility shown. In time it may become viable even with the UK's limited solar energy in winter months.



See also page 65, Properties of Heat – Hot Water. The following additional data has particular application to design of hot water heating systems and components.

CHANGE OF STATE. Water has three basic characteristic states, solid (ice), liquid (fluid) or gas (steam). Water changes state at the specific temperatures of 0°C and 100°C.

LATENT HEAT is the heat energy absorbed or released at the point of change from ice to water and from water to steam, i.e. where there is no change in temperature. This is measured as specific latent heat, in units of joules per kilogram (J/kg).

Specific latent heat of ice = 335 kJ/kg

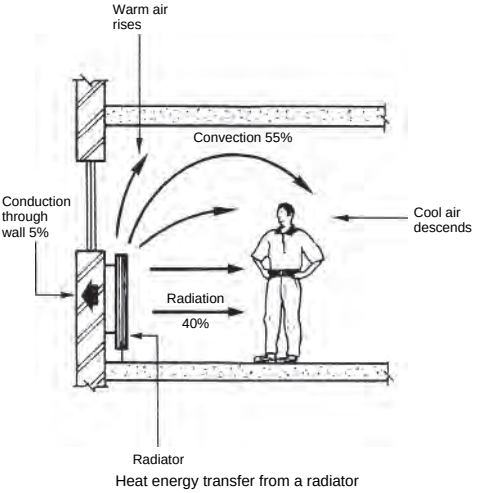
Specific latent heat of water = 2260 kJ/kg

SENSIBLE HEAT is the heat energy absorbed or released during change in temperature.

E.g. to convert 1 kg of ice at 0°C to steam at 100°C:
Ice at 0°C to water at 0°C = 1 kg × 335 kJ/kg = 335 kJ
Water at 0°C to water at 100°C = 1 kg × Shc of water (approx. 4·2 kJ/kg K) × 100 K = 420 kJ
Water at 100°C to steam at 100°C = 1 kg × 2260 kJ/kg = 2260 kJ
The total heat energy will be 335 + 420 + 2260 = 3015 kJ
Note: Total heat is also known as enthalpy.

HEAT ENERGY TRANSFER can be by:

Conduction – heat travelling along or through a material without appreciable change in position of the material particles.
Convection – heat travelling by movement of particles as they expand or contract.
Radiation – heat transfer by electromagnetic waves through space from one material body to another.

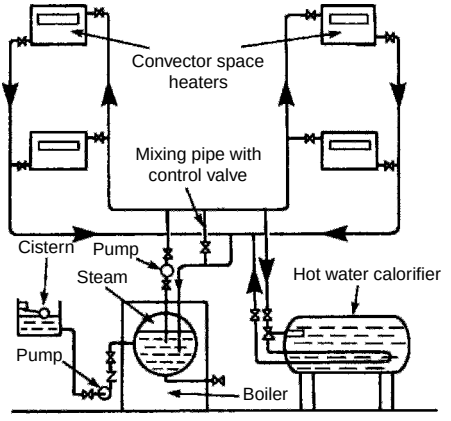


Heat energy transfer from a radiator

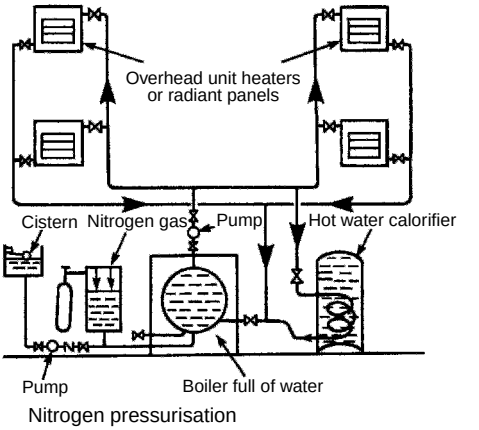
Note: Most heat energy is convected from a radiator, although the term radiator is preferred to differentiate from a convector, where about 90% of heat is convected

Pressurisation allows water to be heated up to 200°C without the water changing state and converting to steam. This permits the use of relatively small diameter pipes and heat emitters, but for safety reasons these systems are only suitable in commercial and industrial situations. Even then, convectors are the preferred emitter as there is less direct contact with the heating surface. Alternatively, radiators must be encased or provision made for overhead unit heaters and suspended radiant panels. All pipes and emitters must be specified to the highest standard.

Water can be pressurised by steam or nitrogen. Pressurised steam is contained in the upper part of the boiler. To prevent the possibility of the pressurised water `flashing´ into steam, a mixing pipe is required between the heating flow and return. Nitrogen gas is contained in a pressure vessel separate from the boiler. It is more popular than steam as a pressurising medium, being easier to control, clean, less corrosive and less compatible with water. Air could be an alternative, but this is more corrosive than nitrogen and water soluble.



Steam pressurisation



Nitrogen pressurisation

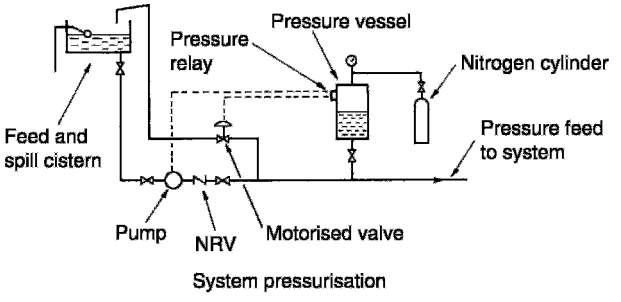
When pressurising with nitrogen it is important that the pressure increases in line with temperature. If it is allowed to deviate the water may `flash', i.e. convert to steam, causing system malfunction and possible damage to equipment.

To commission the system:

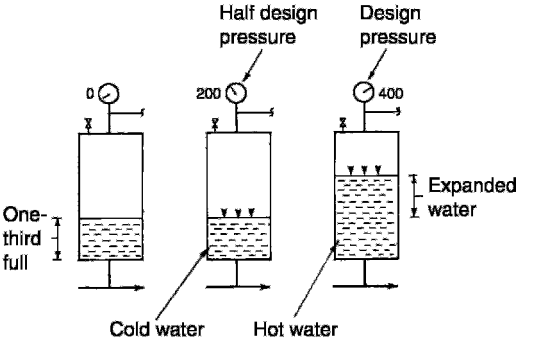
1. Water is pumped from the feed and spill cistern.
2. Air is bled from high levels and emitters.
3. Air is bled from the pressure vessel until the water level is at one-third capacity.
4. Nitrogen is charged into the pressure vessel at half design working pressure.
5. Boiler fired and expansion of hot water causes the water volume and nitrogen pressure in the vessel to double.

Note: Pressure vessel must be carefully designed to accommodate expanded water - approximately 4% of its original volume.

Safety features include a pressure control relay. This opens a motorised valve which lets excess water spill into the feed cistern if the boiler malfunctions and overheats. It also detects low pressure, possibly from system leakage and engages the feed pump to replenish the water and pressure.



System pressurisation



Commissioning pressure vessel

Steam was the energy source of the Victorian era. At this time electricity and associated equipment that we now take for granted were in the early stages of development. Steam was generated in solid fuel boilers to power engines, drive machines and for a variety of other applications, not least as a medium for heat emitters. In this latter capacity it functioned well, travelling over long distances at high velocity (24–36 m/s) without the need for a pump.

By contemporary standards it is uneconomic to produce steam solely for heating purposes. However, it can be used for heating where steam is available from other processes. These include laundering, sterilising, kitchen work, manufacturing and electricity generation. Most of these applications require very high pressure, therefore pressure reducing valves will be installed to regulate supply to heating circuits.

Steam systems maximise the latent heat properties of water when evaporating. This is approximately 2260 kJ/kg at boiling point, considerably more than the sensible heat property of water at this temperature of approximately 420 kJ/kg. Because of this high heat property, the size of heat emitters and associated pipework can be considerably less than that used for hot water systems.

Steam terminology:

Absolute pressure – gauge pressure + atmospheric pressure (101·325 kN/m^2 or kPa).

Latent heat – heat which produces a change of state without a change in temperature, i.e. heat which converts water to steam.

Sensible heat – heat which increases the temperature of a substance without changing its state.

Enthalpy – total heat of steam expressed as the sum of latent heat and sensible heat.

Dry steam – steam which has been completely evaporated, contains no droplets of liquid water.

Wet steam – steam with water droplets in suspension, present in the steam space, typically in pipes and emitters.

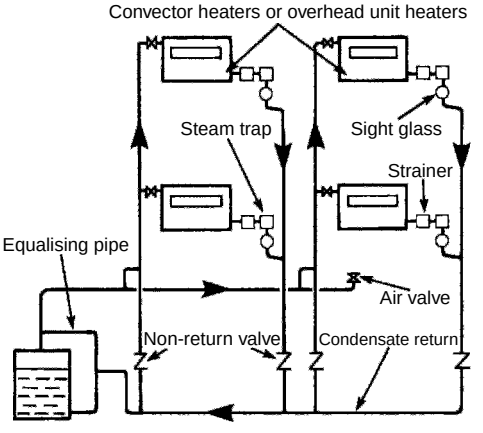
Flash steam – condensate re-evaporating into steam after passing through steam traps.

Saturated steam – steam associated with or in contact with the water in the boiler or steam drum over the boiler.

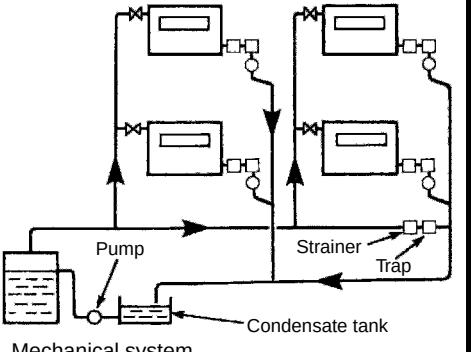
Superheated steam – steam which is reheated or has further heat added after it leaves the boiler.

Classification – low pressure, 35 kPa–170 kPa (108–130°C).
medium pressure, 170 kPa–550 kPa (130–160°C).
high pressure, over 550 kPa (160°C and above).
Note: Gauge pressures shown.

Systems can be categorised as gravity or mechanical. In both, the steam flows naturally from boiler to emitters without the need for a pump. In the mechanical system a positive displacement pump is used to lift condensed steam (condensate) into the boiler. Steam pressure should be as low as possible as this will increase the latent heat capacity. A steam trap prevents energy loss at each emitter. These are fitted with a strainer or filter to contain debris and will require regular cleaning. A sight glass after each trap gives visual indication that the trap is functioning correctly, i.e. only condensate is passing. On long pipe runs a `drip relay' containing steam valve, strainer, trap, sight glass and a gate valve will be required to control condensing steam. This is represented by the strainer and trap in the mechanical system shown below. Expansion loops or bellows will also be required on long pipe runs to absorb thermal movement. All pipework and accessories must be insulated to a very high standard.



Gravity system



Mechanical system

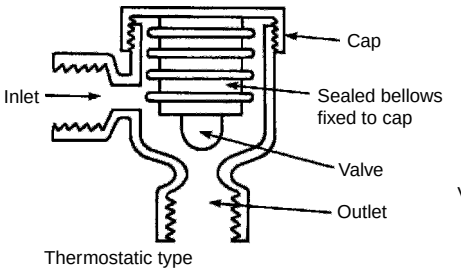
The purpose of a steam trap is to separate steam from condensate, retaining the energy efficient steam in distribution pipework and emitters. Traps are produced in various forms and sizes to suit all situations, some of which are shown below. The thermostatic and bi-metallic types are for relatively small applications such as radiators and unit heaters. The bucket and ball-float types are more suited to separating larger volumes of condensate and steam at the end of long pipe runs and in calorifiers.

Thermostatic – bellows expand or contract in response to steam or condensate repectively. Lower temperature condensate passes through.

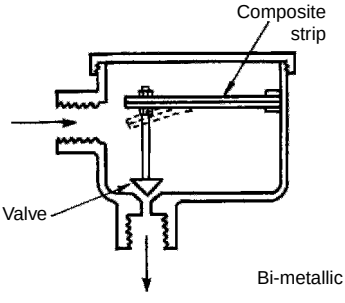
Bi-metallic – condensate flows through the trap until higher temperature steam bends the strip to close the valve.

Bucket – condensate sinks the bucket. This opens the valve allowing steam pressure to force water out until the valve closes.

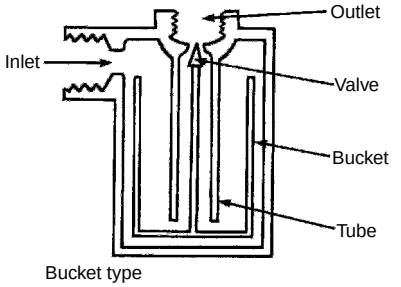
Ball-float – the copper ball rises in the presence of condensate opening the valve to discharge water until steam pressure closes the valve.



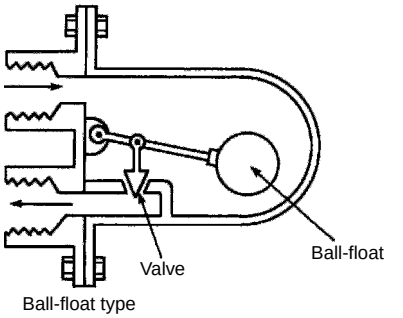
Thermostatic type



Bi-metallic type



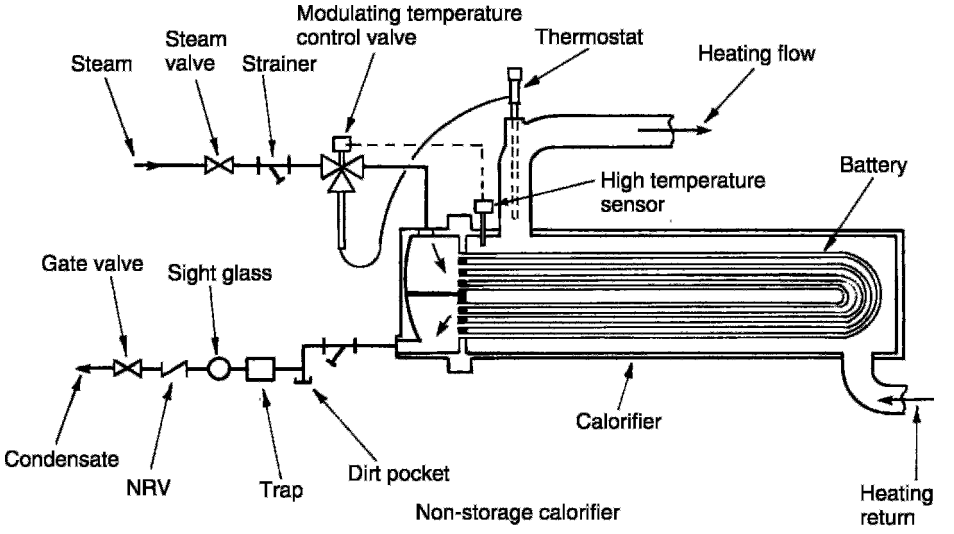
Bucket type



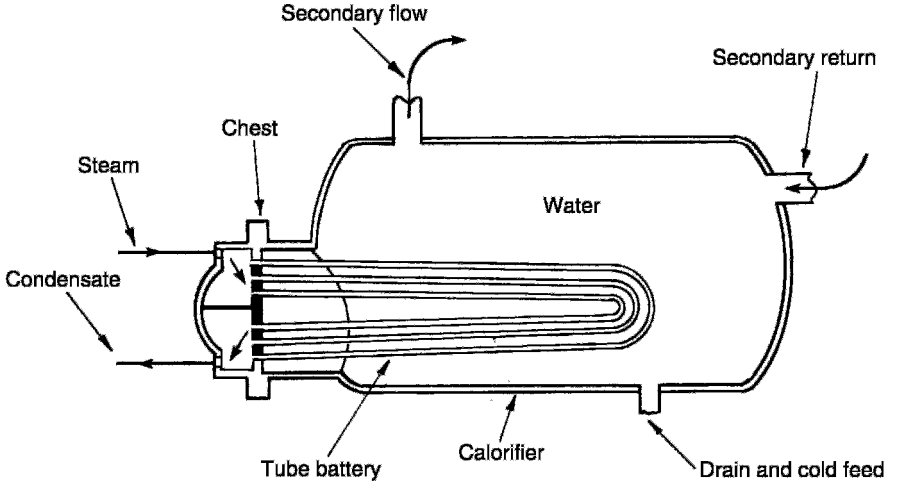
Ball-float type

Non-storage type – used for providing instantaneous hot water for space heating. The steam tube bundle or battery occupies a relatively large area compared to the surrounding amount of water. To avoid temperature override and to control the steam flow, a thermostat and modulating valve must be fitted.

Storage type – these are used to store hot water for manufacturing processes and/or washing demands. Unlike non-storage calorifiers, these have a low steam to water ratio, i.e. a relatively small battery of steam pipes surrounded by a large volume of water.

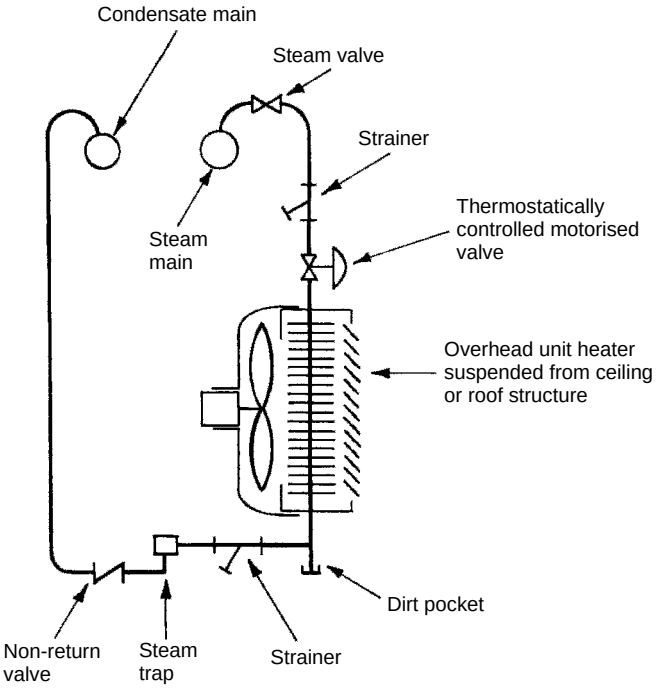


Non-storage calorifier

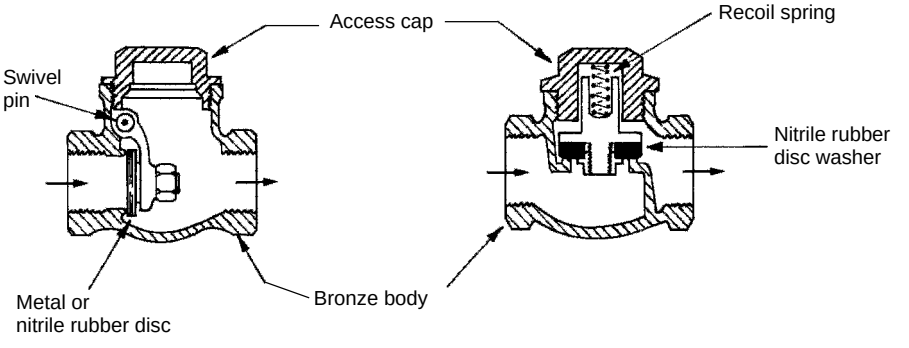


Storage calorifier (controls as above)

High level fan assisted unit heaters are often the preferred means of heat emission for use with steam heating systems. Unless housed, radiators and convectors can be dangerously hot to touch, and they take up useful floor space in industrial production and warehouse premises. A typical installation is shown below with a non-return type of check valve to control the flow of condensate.



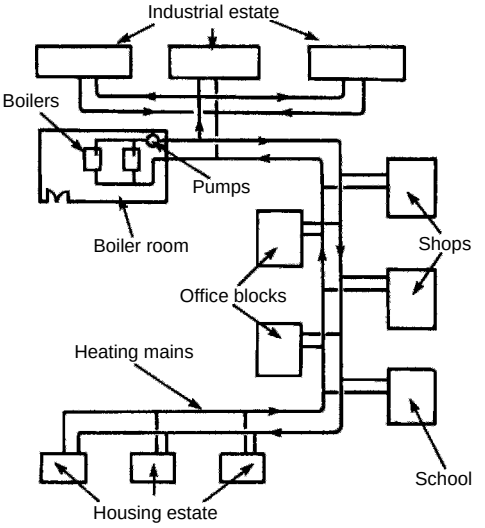
Overhead unit heater connections



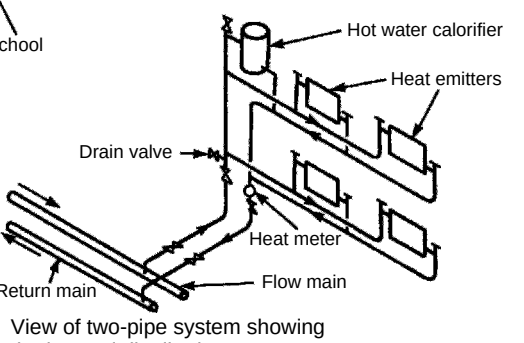
Swing pattern non-return valve

Horizontal lift non-return valve

A district heating system is in principle an enlarged system of heating one building, extended to heat several buildings. It can be sufficiently large enough to heat a whole community or even a small town from one centralised boiler plant. Centralising plant and controls saves space in individual buildings. An effective plant management service will ensure the equipment is functioning to peak efficiency. Each building owner is required to pay a standing charge for the maintenance of plant and to subscribe for heat consumed through an energy metered supply, similar to other utilities. An energy meter differs from a capacity or volume meter by monitoring the heat energy in the water flow, as this will vary in temperature depending on the location of buildings. The boiler and associated plant should be located in close proximity to buildings requiring a high heat load, e.g. an industrial estate. Long runs of heating pipes are required and these must be well insulated. They are normally located below ground but may be elevated around factories. Systems can incorporate industrial waste incinerators operating in parallel with conventional boilers and may also use surplus hot water from turbine cooling processes in power stations or electricity generators. This is known as Combined Heat and Power.



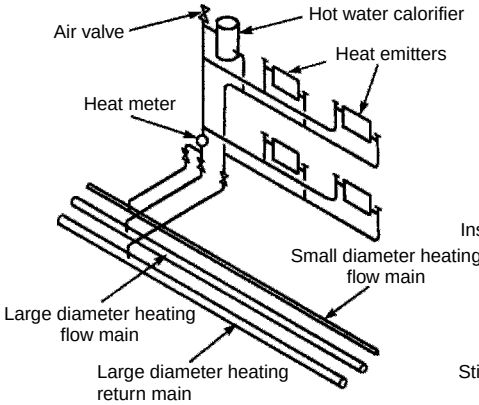
Plan of typical two-pipe scheme



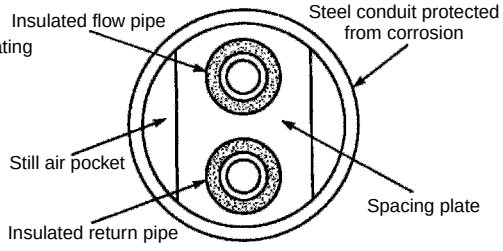
View of two-pipe system showing the internal distribution

The three-pipe system is similar to the two-pipe system except for an additional small diameter flow pipe connected to the boilers. This is laid alongside the larger diameter flow pipe and has a separate circulation pump. This smaller flow pipe is used during the summer months when space heating is not required, although in the intermediate seasons it could supply both with limited application to heating. It should have enough capacity to supply the heating coils in the hot water storage cylinders plus a small reserve. It can be seen as an economy measure to reduce hot water heating volume, energy loss from the larger diameter pipe and pump running costs. A common large diameter return pipe can be used.

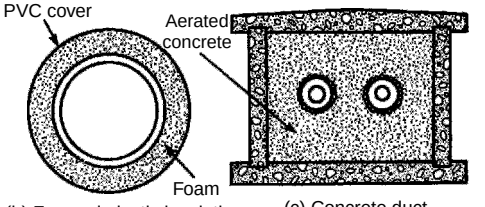
Pipes must be at least 450 mm below the surface as protection from vehicle loads. They must also be well insulated against heat loss and frost damage if water is not circulating. Insulation must be waterproof and the pipes protected from corrosion. Inevitably there will be some heat losses from the mains pipework. This will approximate to 15% of the system heating load.



View of typical three-pipe system showing the internal distribution



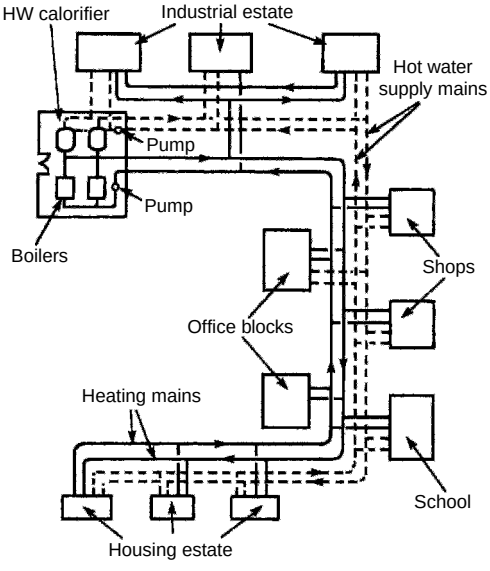
(a) Pipes inside steel conduit



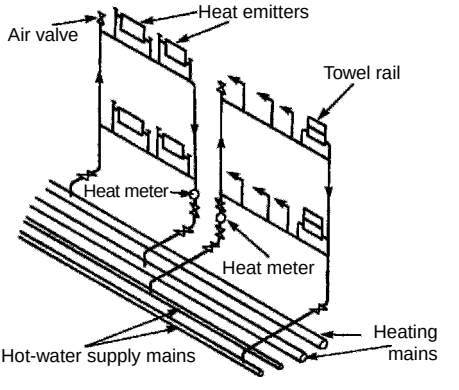
(b) Foamed plastic insulation (c) Concrete duct

Underground heating mains

The four-pipe system supplies both hot water and space heating as two separate systems. Individual hot water storage cylinders are not required, as large capacity calorifiers are located in the boiler plant room and possibly at strategic locations around the district being served. This considerably simplifies the plumbing in each building as cold water storage cisterns are also unnecessary, provided all cold water outlets can be supplied direct from the main. However, the boiler plant room will be considerably larger to accommodate the additional components and controls. Excavation and installation costs will also be relatively expensive, but system flexibility and closure of the heating mains and associated boilers during the summer months should provide economies in use.



Plan of typical four-pipe system

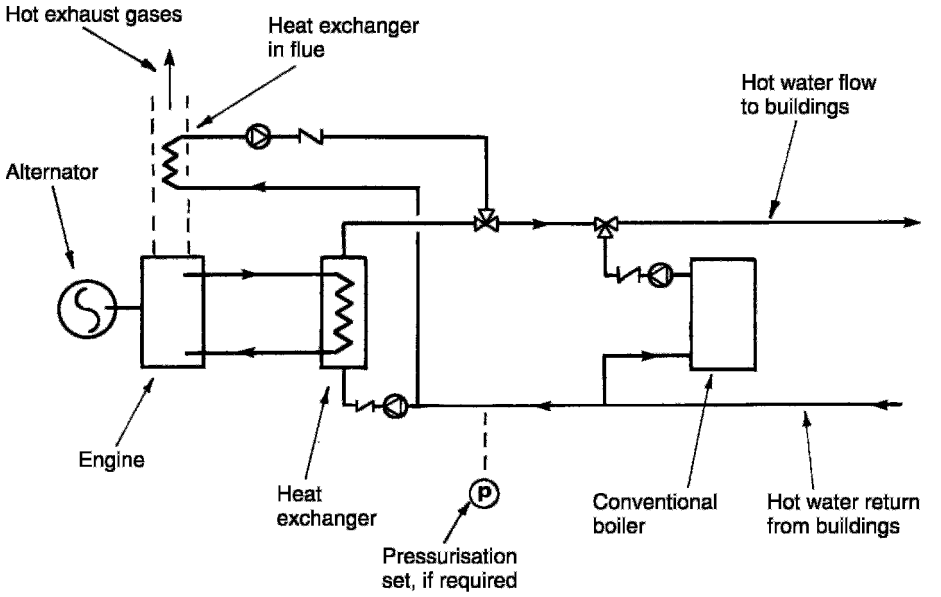


View of typical four-pipe system

Potential for more economic use of electricity generating plant can be appreciated by observing the energy waste in the large plumes of condensing water above power station cooling towers. Most power stations are only about 50% efficient, leaving a considerable margin for reprocessing the surplus hot water.

Combining electricity generation with a supply of hot water has become viable since the deregulation and privatisation of electricity supply. Prior to this, examples were limited to large factory complexes and remote buildings, e.g. prisons, which were independent of national power generation by special licence. Until the technology improves, it is still only practical for large buildings or expansive collections of buildings such as university campuses and hospitals.

Surplus energy from oil- or gas-fired engine driven alternators occurs in hot water from the engine cooling system and the hot exhaust gases. In a CHP system the rate of heat energy produced is directly related to the amount of electricity generated. There will be times when available hot water is insufficient. Therefore a supplementary energy source from a conventional boiler will be required.



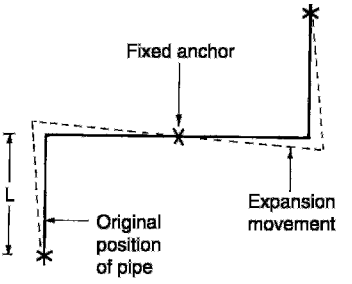
Principles of CHP

All pipe materials expand and contract when subject to temperature change. This linear change must be accommodated to prevent fatigue in the pipework, movement noise, dislocation of supports and damage to the adjacent structure.

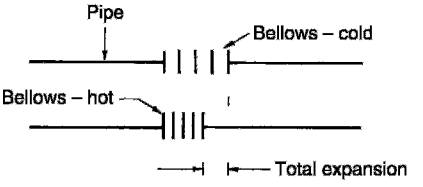
Expansion devices:

- Natural changes in direction.
- Axial expansion bellows.
- Expansion loops.

Bellows and loops are not normally associated with domestic installations.

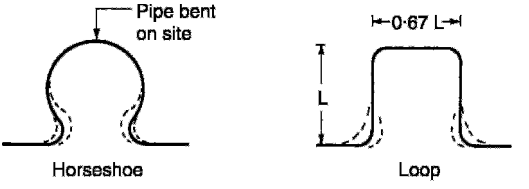


Natural changes in direction or offsets



Axial expansion bellows responding to hot water

Bellows are factory-made fittings normally installed 'cold-drawn' to the total calculated expansion for hot water and steam services. The bellows can then absorb all anticipated movement by contraction. Where the pipe content is cold or refrigerated fluids, the bellows are compressed during installation.



Site made loops or horseshoe

Coefficients of linear expansion for common pipework materials:

Material	Coeff. of expansion ($m/mK \times 10^{-6}$)
Cast iron	10·22
Copper	16·92
Mild steel	11·34
PVC (normal impact)	55·10
PVC (high impact)	75·10
Polyethylene (low density)	225·00
Polyethylene (high density)	140·20
ABS (acrylonitrile butadiene styrene)	110·20

E.g. An 80 mm diameter steel pipe of 20 m fixed length is subject to a temperature increase from 20°C to 80°C (60 K).

Formula:

Expansion = Original length × coeff. of expansion × Temp. diff.

$= 20 \times 11{\cdot}34 \times 10^{-6} \times 60$

$= 0{\cdot}0136$ m or 13·6 mm

Single offset:

$L = 100\ \sqrt{zd}$

L = see previous page

z = expansion (m)

d = pipe diameter (m)

$L = 100\ \sqrt{0{\cdot}0136} \times 0{\cdot}080 = 3{\cdot}30$ m minimum.

Loops:

$L = 50\ \sqrt{zd}$

$L = 50\ \sqrt{0{\cdot}0136} \times 0{\cdot}080 = 1{\cdot}65$ m minimum.

Top of loop = 0·67 × L = 1·10 m minimum.

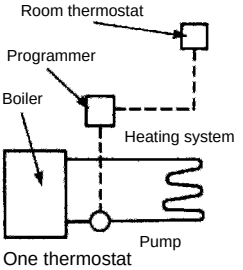
Notes:

- Provide access troughs or ducts for pipes in screeds (Part 14).
- Sleeve pipework through holes in walls, floors and ceilings (see pages 325 and 520 for fire sealing).
- Pipework support between fixed anchors to permit movement, i.e. loose fit brackets and rollers.
- Place felt or similar pads between pipework and notched joists.
- Branches to fixtures to be sufficient length and unconstrained to prevent dislocation of connections.
- Allow adequate space between pipework and structure.

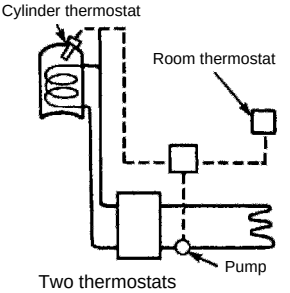
Thermostatic control of heating and hot water systems reduces consumers' fuel bills, regulates the thermal comfort of building occupants and improves the efficiency of heat producing appliances. Approved Document L to the Building Regulations effects these provisions. This has the additional objective of limiting noxious fuel gases in the atmosphere and conserving finite natural fuel resources.

A room thermostat should be sited away from draughts, direct sunlight and heat emitters, at between 1·2 and 1·5 m above floor level. Thermostatic radiator valves may also be fitted to each emitter to provide independent control in each room. A less expensive means of controlling the temperature in different areas is by use of thermostatically activated zone valves to regulate the temperature of individual circuits.

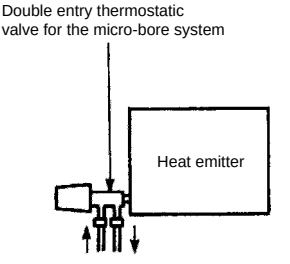
Three-port thermostatic valves may be either mixing or diverting. The mixing valve has two inlets and one outlet. The diverting valve has one inlet and two outlets. Selection will depend on the design criteria, as shown in the illustrations.



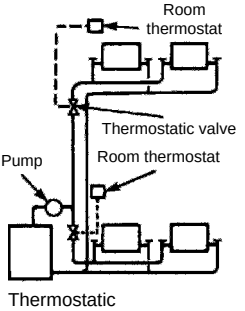
One thermostat controlling the pump



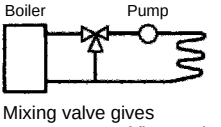
Two thermostats controlling the pump to give priority to hot water supply



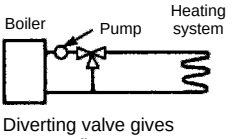
Thermostatic radiator valve



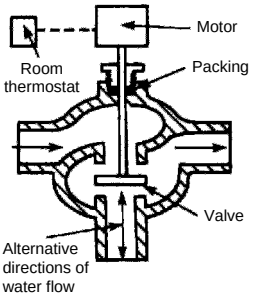
Thermostatic zoning valves



Mixing valve gives constant rate of flow and variable flow temperature



Diverting valve gives constant flow temperature and variable flow

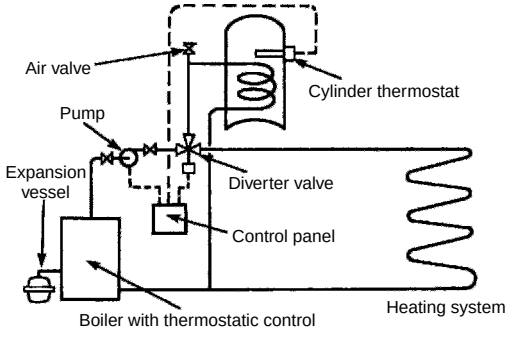


Section through a three-port valve operated by a room thermostat

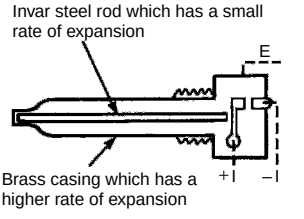
The diverter valve may be used to close the heating circuit to direct hot water from the boiler to the hot water cylinder. The reverse is also possible, depending on whether hot water or heating is considered a priority. With either, when the thermostat on the priority circuit is satisfied it effects a change in the motorised diverter valve to direct hot water to the other circuit.

A rod-type thermostat may be fitted into the hot water storage cylinder, or a surface contact thermostat applied below the insulation. At the pre-set temperature (about 60°C) a brass and invar steel strip expands to break contact with the electricity supply. A room thermostat also operates on the principle of differential expansion of brass and invar steel. Thermostatic radiator valves have a sensitive element which expands in response to a rise in air temperature to close the valve at a pre-set temperature, normally in range settings 5–27°C. Sensors are either a thermostatic coil or a wax or liquid charged compartment which is insulated from the valve body.

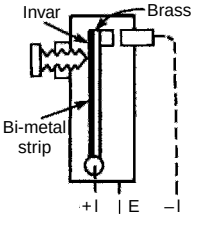
A clock controller sets the time at which the heating and hot water supply will operate. Programmers are generally more sophisticated, possibly incorporating 7 or 28-day settings, bypass facilities and numerous on/off functions throughout the days.



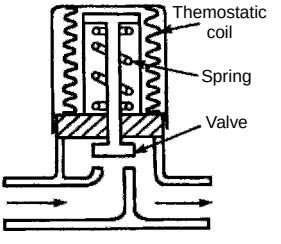
Use of diverter valve to give priority to hot water supply to a system having a pumped circuit to both the heating and the hot water cylinder



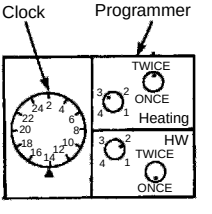
Rod type thermostat



Room thermostat



Thermostatic radiator valve



Clock control and programmer

Ref. Building Regulations, Approved Document L1: Conservation of fuel and power in dwellings –

From 2002 it has been mandatory in the UK to provide a higher standard of controls for hot water and heating installations. This is to limit consumption of finite fuel resources and to reduce the emission of atmospheric pollutants. All new installations and existing systems undergoing replacement components are affected.

Requirements for 'wet' systems –

- Only boilers of a minimum efficiency can be installed. See SEDBUK values on page 72 and 74.

- Hot water storage cylinders must be to a minimum acceptable standard, i.e. BSs 1566 and 3198: Copper indirect cylinders and hot water storage combination units for domestic purposes, respectively for vented systems. BS 7206: Specification for unvented hot water storage units and packages, for sealed systems. Vessels for unvented systems may also be approved by the BBA, the WRc or other accredited European standards authority. See pages 534 and 535.

- New systems to be fully pumped. If it is impractical to convert an existing gravity (convection) hot water circulation system, the heating system must still be pumped, i.e. it becomes a semi-gravity system, see pages 108 and 112. Existing system controls to be upgraded to include a cylinder thermostat and zone (motorised) valve to control the hot water circuit temperature and to provide a boiler interlock. Other controls are a programmer or clock controller, a room thermostat and thermostatic radiator valves (TRVs to BS EN 215) in the bedrooms.

Note: The boiler is said to be 'interlocked' when switched on or off by the room or cylinder thermostat (or boiler energy management system). The wiring circuit to and within the boiler and to the pump must ensure that both are switched off when there is no demand from the hot water or heating system, i.e. the boiler must not fire unnecessarily even though its working thermostat detects the water content temperature to be below its setting.

continued . . . . . .

Requirements for `wet´ systems (continued) –

- Independent/separate time controls for hot water and space heating. The exceptions are:

  (1) combination boilers which produce instantaneous hot water, and
  (2) solid fuel systems.

- Boiler interlock to be included to prevent the boiler firing when no demand for hot water or heating exists.

- Automatic by-pass valve to be fitted where the boiler manufacturer specifies a by-pass circuit.

  Note: A circuit by-pass and automatic control valve is specified by some boiler manufacturers to ensure a minimum flow rate whilst the boiler is firing. This is particularly useful where TRVs are used, as when these begin to close, a by-pass valve opens to maintain a steady flow of water through the boiler. An uncontrolled open by-pass or manually set by-pass valve is not acceptable as this would allow the boiler to operate at a higher temperature, with less efficient use of fuel.

- Independent temperature control in living and sleeping areas (TRVs could be used for bedroom radiators).

- Installations to be inspected and commissioned to ensure efficient use by the local authority Building Control Department or self-certified by a `competent person´, i.e. CORGI, OFTEC or HETAS approved (see page 73).

- System owners/users to be provided with equipment operating guides and maintenance instructions. This `log-book´ must be completed by a `competent person´.

- Dwellings with over 150 m^2 living space/floor area to have the heating circuits divided into at least two zones. Each to have independent time and temperature control and to be included in the boiler interlock arrangement. A separate control system is also required for the hot water.

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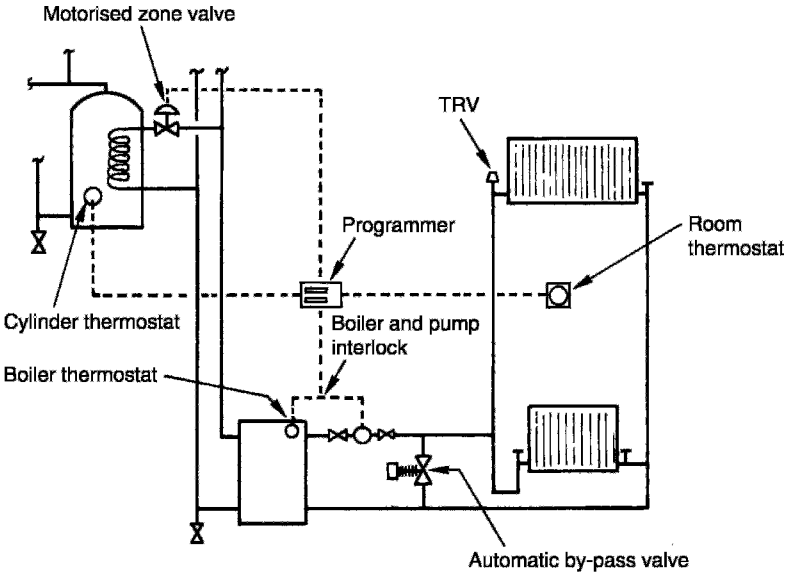
Requirements for `dry' systems –

- Warm air or dry systems (see page 122) should also benefit fully from central heating controls. Although gas-fired air heaters are not covered by SEDBUK requirements, these units should satisfy the following standards:

  BS EN 778: Domestic gas-fired forced convection air heaters for space heating not exceeding a net heat input of 70 kW, without a fan to assist transportation of combustion air and/or combustion products, or

  BS EN 1319: Domestic gas-fired forced convection air heaters for space heating, with fan-assisted burners not exceeding a net heat input of 70 kW.

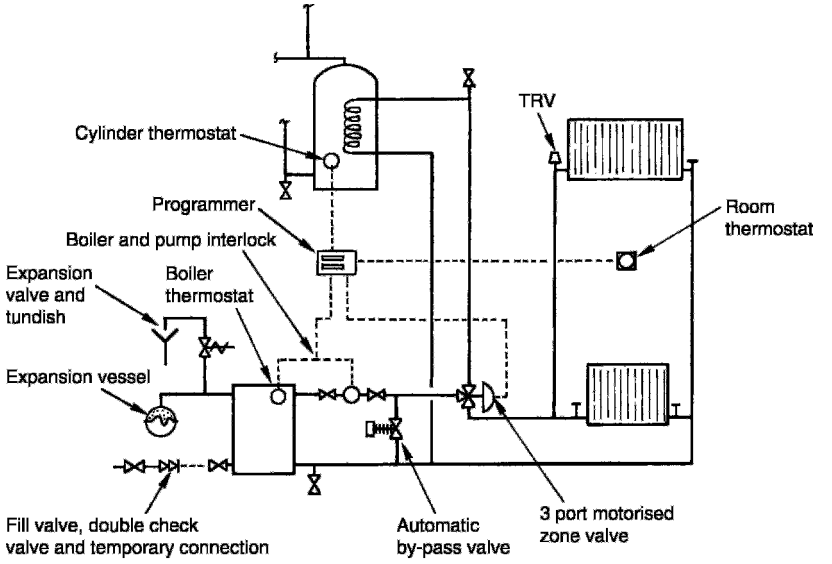
- Replacement warm air heat exchanger units can only be fitted by a `competent person'. All newly installed ducting should be fully insulated.



Note: Boiler and pump interlock is the wiring configuration as explained on the previous two pages

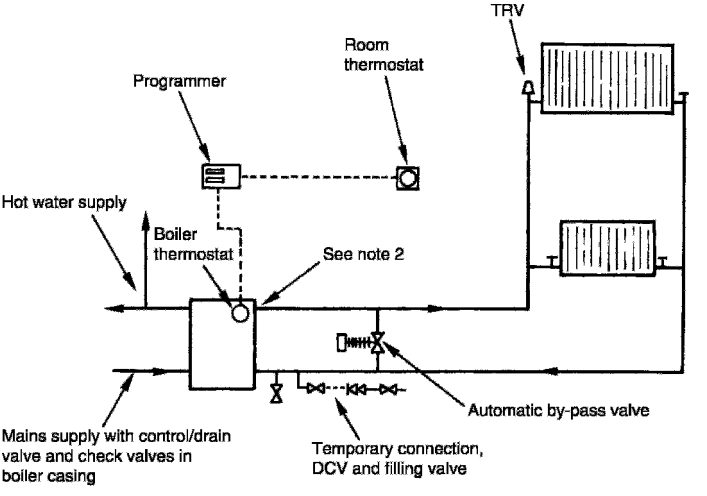
Typical semi-gravity system of hot water and heating controls

Schematic of control systems –



Note: Boiler and pump interlock is the wiring configuration as explained on pages 110 and 111

Typical fully pumped system of hot water and heating



Notes:
1. Hot water draw off taps supplied direct from mains, through instantaneous water heater
2. Heating water is sealed. Additional components include heating pump and expansion vessel in boiler casing, with expansion valve and tundish (see upper diagram)

Typical combination boiler (see also page 54)

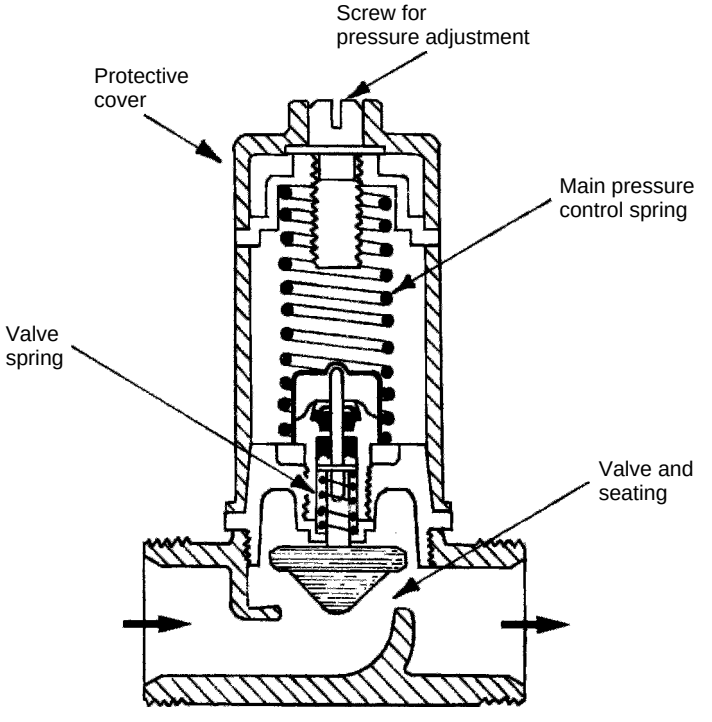
Automatic By-pass Control

Modern boilers and heating systems are low water content to provide fuel efficiency and a rapid response. Therefore, to maintain a minimum flow through the boiler and to accommodate pump over-run, most boiler manufacturers will specify that a system by-pass be used with their products.

An open by-pass or by-pass with a valve set in a fixed open position will satisfy the basic objectives, but with the boiler flow pipe feeding the return pipe at all operating times, the boiler will need to function at a higher temperature than necessary to fulfil system requirements. Also, the heat energy transferred into the system will be limited, as a proportion of boiler flow water will be continually diverted through the by-pass pipe.

Thermostatically controlled radiator valves and motorised zone and circuit valves are now standard installation. With these controls parts of the system may be closed, leaving only a limited demand for heat. Selective demands will cause varying pump pressures, unless a by-pass valve is in place to automatically adjust, regulate and respond to pressure changes from the pump. Some applications are shown on the previous two pages.

Typical automatic by-pass valve –

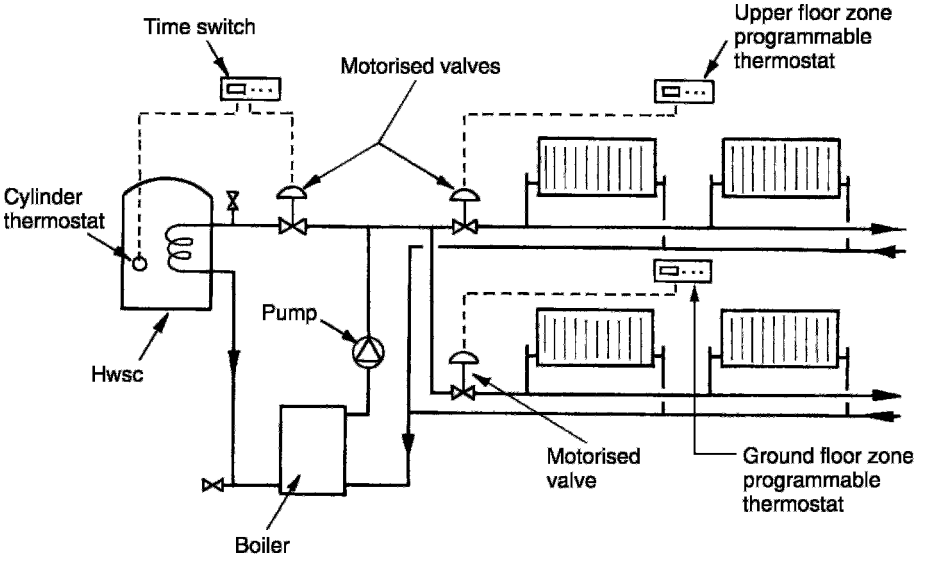


In addition to high efficiency boilers, optimiser controls, thermostatic radiator valves and other fuel-saving measures considered elsewhere in this chapter, further economies and user comforts can be achieved by installing programmable thermostats with motorised valves dedicated to heat only a specific part or zone within a building.

Zone control or zoning provides fuel saving and user convenience by regulating heat/energy distribution to particular locations in response to occupancy. This prevents wasteful distribution of heat in a building that is not fully utilised.

Examples where zoning has greatest benefit:

- Unused upper floor rooms, i.e. bedrooms, during daytime.
- Supplementary accommodation, bedsit or granny flat.
- Conservatories or other rooms with heating characteristics which are weather and seasonally variable.
- Office in the home, occupied whilst the remainder of the house is not.
- People with irregular working patterns, i.e. shift workers may require heating downstairs when others will not.
- Insomniacs and people who get up regularly in the night (the elderly?) may require heating in a specific room at unusual times.



Note: See page 91 for boiler feed/fill and expansion facilities

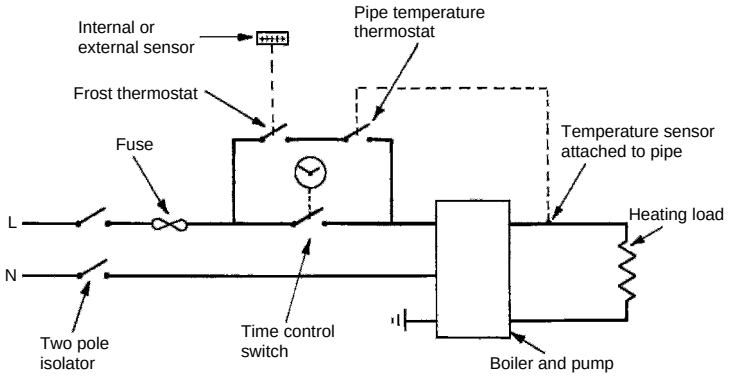
Example using zone control programmable thermostats with 'wireless' (radio frequency signals) regulation of the boiler

Piped water systems in modern highly insulated buildings are unlikely to be affected by modest sub-zero external temperatures. Nevertheless, an automatic 24-hour frost damage fail-safe facility may be specified as a client requirement or to satisfy insurer's standards. This is particularly appropriate for buildings located in very exposed parts of the country, and for buildings that are periodically unoccupied.

Frost thermostat – similar in appearance to a normal room thermostat but with a lower temperature range. Installed internally or externally on a north facing wall and set to about 5°C.

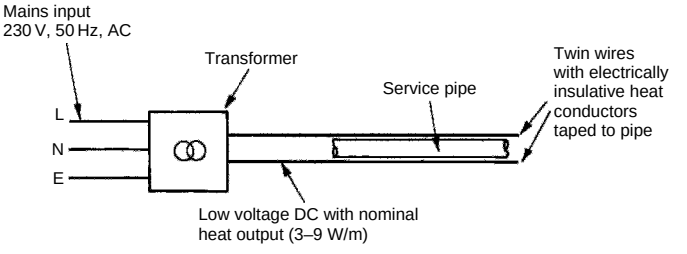
Pipe thermostat – strapped to an exposed section of pipe to detect the temperature of the contents.

Both types of thermostat can be used independently or wired in series to the same installation as shown below. Whether used in combination or individually, they are installed to by-pass the time control.



Thermostatic frost protection

Trace element frost protection – a low voltage electric heating element taped to the pipe surface. Used mainly for external piped services.



Trace element heating

Wireless or radio frequency (RF) band communications are in common use. For example, remote keyless entries, TV controls, portable telephones, burglar alarm systems, garage doors, estate gates and computer links. For heating system controls, this form of communications technology offers many benefits to both installer and property owner/end user. Not least a saving in installation time, as hard wiring between thermostatic controls, boiler controls, motorised valves and programmer is not required. There is also considerably less disruption to the structure and making good the superficial damage from channelling walls, lifting floorboards, drilling walls and holing joists. This is particularly beneficial where work is applied to existing buildings and refurbishment projects.

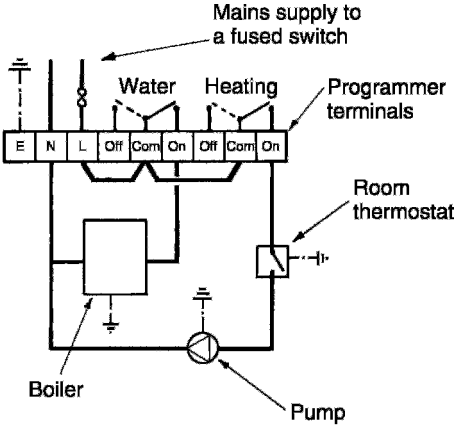
In principle, a battery cell power source is used to transmit a secure, unique radio signal from the hot water storage cylinder thermostat and each of the room thermostats. This signal is recognised by a receiver which is hard-wired to switching units placed next to the boiler, pump and motorised valves. Installation cabling is therefore reduced to an absolute minimum at localised receivers only. The appearance and location of thermostats is similar to conventional hard-wired units. The capital cost of components is significantly more, but the savings in installation time will justify this expenditure.

The use of radio frequencies for communications systems in modern society is strictly controlled and regulated by operator licensing regulations to prevent interference and cross communications. For wireless domestic heating controls this is not a problem as the unique low power signals function at around 430 MHz at a short range, typically up to 30 metres. At this specification, an operating license is not required as it satisfies the recommendations of the European Telecommunications Standards Institute, European Standard EN 300-220 for equipment in the 25 to 1000 Mhz frequency band at power levels up to 500 mW.

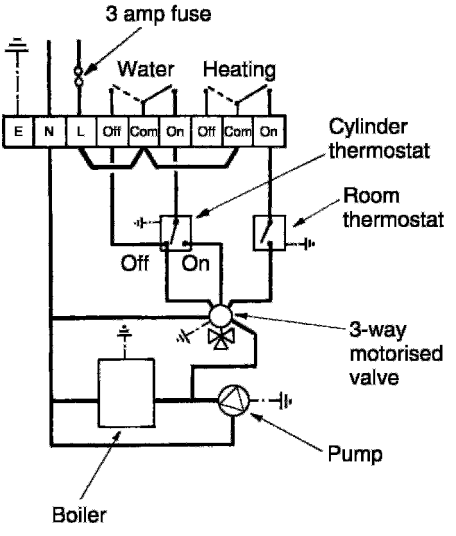
To commission RF controls, each thermostat is digitally coded and programmed to the associated signal receiver. Therefore, the controls in one building will not interfere with similar controls in adjacent buildings, and vice versa. Siting of controls will require some care, as large metal objects can inhibit the signalling function. Location of the boiler and hot water storage cylinder are obvious examples that will need consideration.

There are a variety of wiring schemes depending on the degree of sophistication required and the extent of controls, i.e. thermostats, motorised valves, etc. Boiler and control equipment manufacturers provide installation manuals to complement their products. From these the installer can select a control system and wiring diagram to suit their client's requirements.

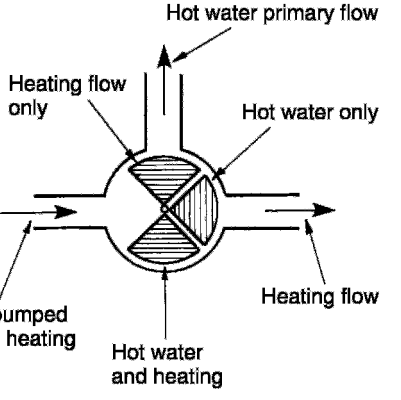
The schematic diagrams shown relate to a gravity or convected primary flow and return and pumped heating system (see page 84) and a fully pumped hot water and heating system using a three-way motorised valve (see page 109).



Gravity primary flow and return, pumped heating system



Fully pumped system

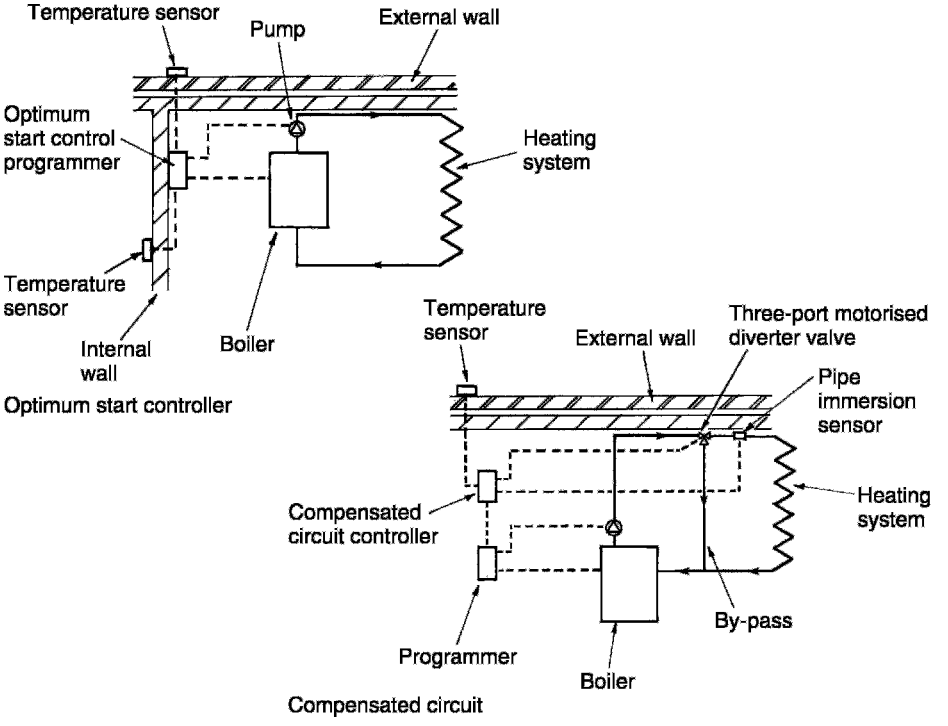


Theoretical operation of 3-port motorised valve.
Note: may be installed to give hot water priority over heating.

Optimum Start Controls – these have a control centre which computes the building internal temperature and the external air temperature. This is used to programme the most fuel efficient time for the boiler and associated plant to commence each morning and bring the building up to temperature ready for occupation. The system may also have the additional function of optimising the system shutdown time.

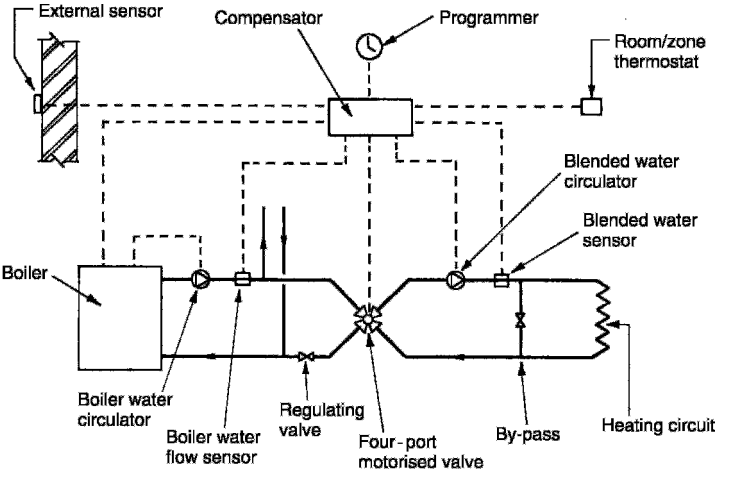
Compensated Circuit – this system also has a control centre to compute data. Information is processed from an external thermostat/ sensor and a heating pipework immersion sensor. The principle is that the boiler water delivery temperature is varied relative to outside air temperature. The warmer the external air, the cooler the system water and vice versa.

The capital cost of equipment for these systems can only be justified by substantial fuel savings. For large commercial and industrial buildings of variable occupancy the expenditure is worthwhile, particularly in the intermediate seasons of autumn and spring, when temperatures can vary considerably from day to day.



Weather compensated circuit – accurate control of indoor temperature depends on monitoring and modulating system heat input with the heat losses from a building. This differs considerably from the traditional heating system controlled solely by a thermostat. A thermostat functions relative to internal air temperature, switching on the boiler to supply water at a pre-set temperature.

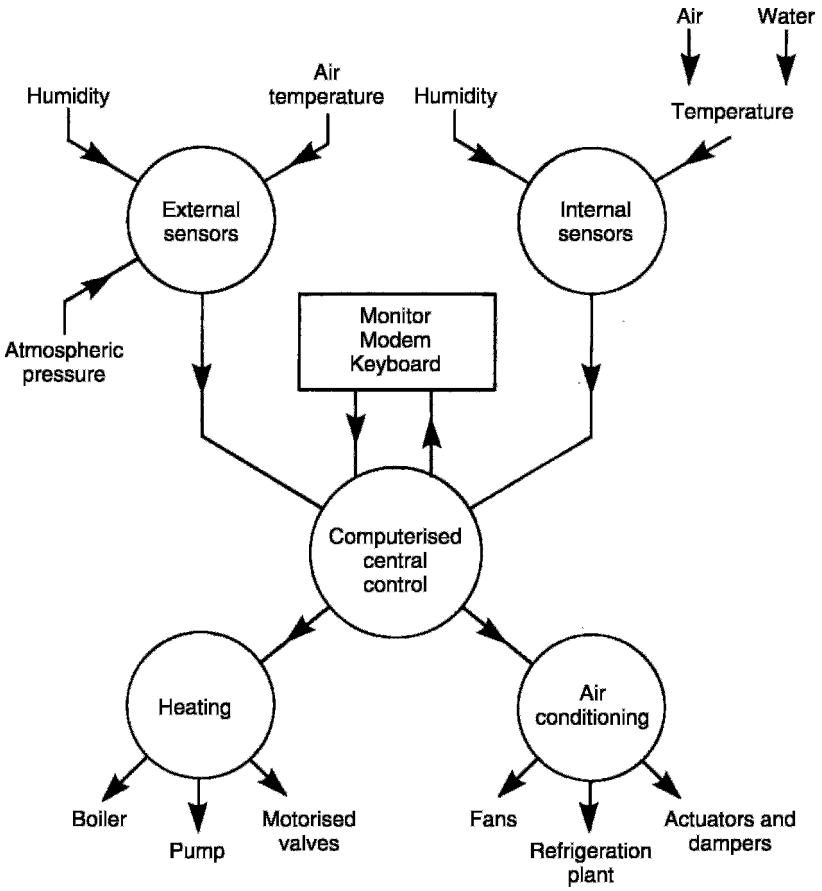
Optimum comfort and economy are achieved if the heating system water is constantly circulated with temperature varied to suit occupancy needs. A balance is achieved by incorporating into the heating programme, the external air temperature and internal heat gains from people, machinery, solar sources, etc. At the centre of the installation is a compensator-controlled 3- or 4-port motorised valve (3 port shown on previous page). This valve blends the required amount of cool system return water with hot water supplied from the boiler, to ensure a continuous supply of water at the required temperature to satisfy ambient conditions. The motorised valve setting varies depending on the boiler water temperature, the system supply water temperature, internal air temperature and outdoor air temperature. The latter is measured by a thermostatic sensor fitted to a north facing wall. Data from all four sources is computed in the compensator for positioning the motorised valve, activating the system circulator and to regulate the boiler functions.



Weather compensated control system

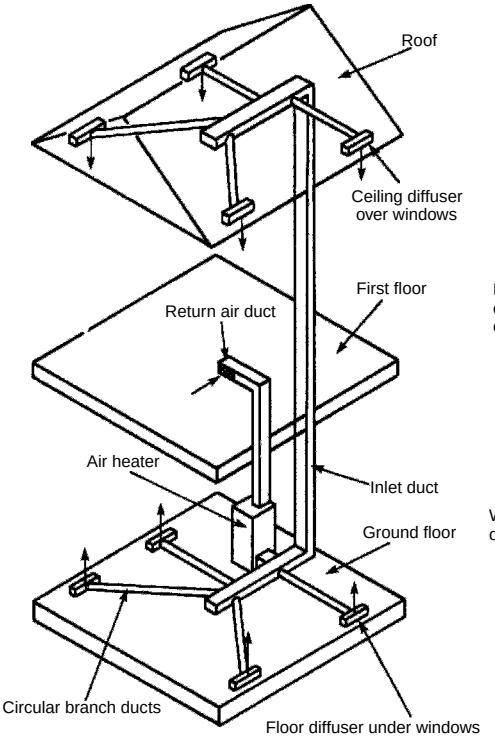
Note: Variable water temperature systems are particularly suited to underfloor heating. The heating demand is more evenly controlled through the `thermal' floor than by on-off thermostatic switching.

Energy management systems can vary considerably in complexity and degree of sophistication. The simplest timing mechanism to switch systems on and off at pre-determined intervals on a routine basis could be considered as an energy management system. This progresses to include additional features such as programmers, thermostatic controls, motorised valves, zoning, optimum start controllers and compensated circuits. The most complex of energy management systems have a computerised central controller linked to numerous sensors and information sources. These could include the basic internal and external range shown schematically below, along with further processed data to include: the time, the day of the week, time of year, percentage occupancy of a building, meteorological data, system state feedback factors for plant efficiency at any one time and energy gain data from the sun, lighting, machinery and people.

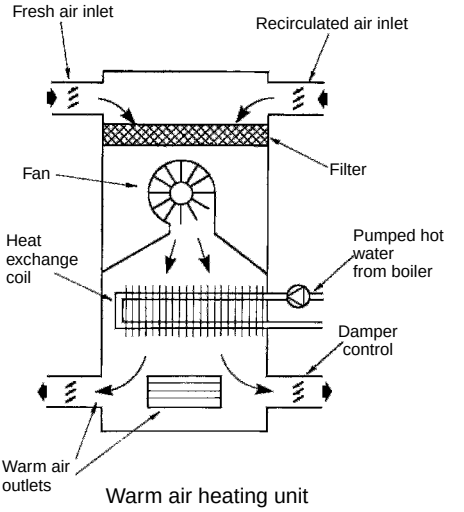


Schematic of energy management components

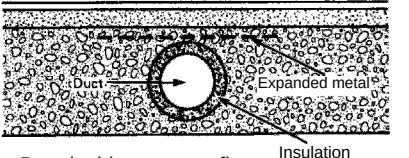
If there is sufficient space within floors and ceilings to accommodate ducting, warm air can be used as an alternative to hot water in pipes. There are no obtrusive emitters such as radiators. Air diffusers or grilles with adjustable louvres finish flush with the ceiling or floor. The heat source may be from a gas, oil or solid fuel boiler with a pumped supply of hot water to a heat exchanger within the air distribution unit. The same boiler can also be used for the domestic hot water supply. Alternatively, the unit may burn fuel directly, with air delivered around the burner casing. Control is simple, using a room thermostat to regulate heat exchanger and fan. The risk of water leakage or freezing is minimal, but air ducts should be well insulated to reduce heat losses. Positioning grilles in doors is an inexpensive means for returning air to the heater, but a return duct is preferred. Fresh air can be supplied to rooms through openable windows or trickle ventilators in the window frames. If rooms are completely sealed, fresh air should be drawn into the heating unit. The minimum ratio of fresh to recirculated air is 1:3.



System for a house



Warm air heating unit



Duct inside concrete floor

The thermal transmittance rate from the inside to the outside of a building, through the intermediate elements of construction, is known as the 'U' value. It is defined as the energy in watts per square metre of construction for each degree Kelvin temperature difference between inside and outside of the building, i.e. W/m^2 K. The maximum acceptable 'U' values vary with building type and can be found listed in Approved Documents L1 and L2 to the Building Regulations.

Typical maximum area weighted average* 'U' values for dwellings:

External walls	0·35
Pitched roof	0·16
Pitched roof containing a room	0·20
Flat roof	0·25
External floor	0·25
Windows, doors and rooflights	2·00 (ave.) Wood/uPVC
Windows, doors and rooflights	2·20 (ave.) Metal

Note: Windows, doors and rooflights, maximum 25% of floor area.

Non-domestic buildings also have a maximum 'U' value of 1·5 for vehicle access doors, along with the following requirements for windows, doors and rooflights:

Residential buildings – maximum 30% of exposed wall internal area.

Industrial and storage buildings – max. 15% of exposed wall internal area.

Places of assembly, offices and shops – maximum 40% of exposed wall internal area.

Rooflights – maximum 20% of rooflight to roof area.

E.g. A room in a dwelling house constructed to have maximum 'U' values has an external wall area of 30 m^2 to include 3 m^2 of double glazed window. Given internal and external design temperatures of 22°C and −2°C respectively, the heat loss through this wall will be:

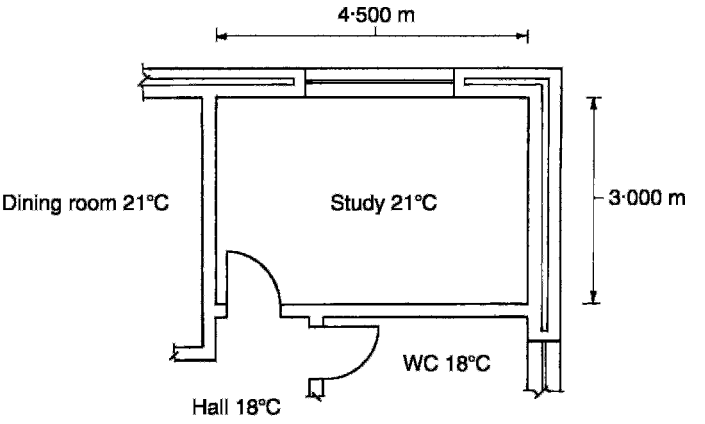
	Area × 'U' × temperature difference	
Wall:	27 × 0·35 × 24 =	226·80
Window:	3 × 2·00 × 24 =	144·00
		370·80 watts

*Note: Area weighted average allows for interruption in the construction, e.g. meter cupboard voids.

A heat emitter should be capable of providing sufficient warmth to maintain a room at a comfortable temperature. It would be uneconomical to specify radiators for the rare occasions when external temperatures are extremely low, therefore an acceptable design external temperature for most of the UK is −1°C. Regional variations will occur, with a figure as low as −4°C in the north. The following internal design temperatures and air infiltration rates are generally acceptable:

Room	Temperature 0°C	Air changes per hour
Living	21	1·5
Dining	21	1·5
Bed/sitting	21	1·5
Bedroom	18	1·0
Hall/landing	18	1·5
Bathroom	22	2·0
Toilet	18	2·0
Kitchen	18	2·0

The study in the part plan shown below can be used to illustrate the procedure for determining heat losses from a room.



External design temperature −1°C
Room height = 2·3 m
Door area = 2 m^2
Window area = 1·5 m^2
Ventilation rate = 1·5 a/c per hour
Bedrooms above at 18°C

To determine the total heat loss or heating requirement for a room, it is necessary to obtain the thermal insulation properties of construction. For the room shown on the previous page, the 'U' values can be taken as:

External wall	0·35 W/m^2 K
Window	2·00
Internal wall	2·00
Door	4·00
Floor	0·25
Ceiling	2·50

Heat is also lost by air infiltration or ventilation. This can be calculated and added to the heat loss through the structure, to obtain an estimate of the total heating requirement.

Heat loss by ventilation may be calculated using the following formula:

$$\text{Watts} = \frac{\text{Room volume} \times \text{A/c per hour} \times \text{Temp. diff. (int. - ext.)}}{3}$$

Note: The lower denomination 3, is derived from density of air (1·2 kg/m^3) × s.h.c. of air (1000 J/kg K) divided by 3600 seconds.

For the study shown on the previous page:

(4·5 × 3 × 2·3) × 1·5 × (21 – –1) divided by 3 = 341·55 watts

Heat loss through the structure is obtained by summating the elemental losses:

Element	Area (m^2)	'U' value	Temp. diff. (int. – ext.)	Watts
External wall	15·75 ×	0·35 ×	22	= 121·28
Window	1·5	2·00	22	66
Internal wall	8·35	2·00	3	50·10
Door	2	4·00	3	24
Floor	13·5	0·25	22	74·25
Ceiling	13·5	2·50	3	101·25
				436·88

Total heat loss from the study = 341·55 + 436·88 = 778·43, i.e. 779 watts

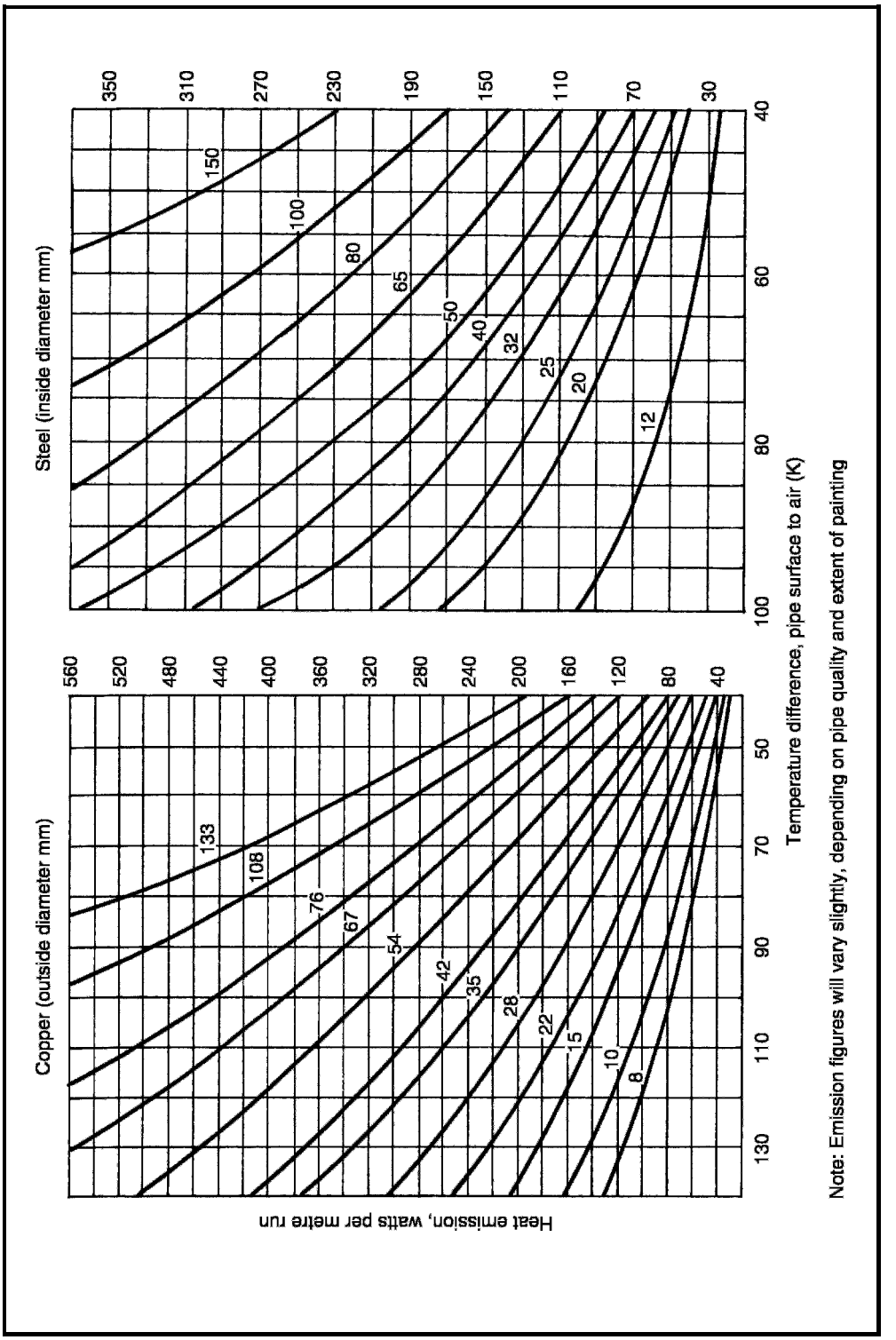
Radiators are specified by length and height, number of sections, output in watts and number of panels. Sections refer to the number of columns or verticals in cast iron radiators and the number of corrugations in steel panel radiators. Panels can be single, double or triple. Design of radiators and corresponding output will vary between manufacturers. Their catalogues should be consulted to determine exact requirements. The following extract shows that a suitable single panel radiator for the previous example of 779 watts, could be:

450 mm high × 1100 mm long × 33 sections (832 watts), or
600 mm high × 800 mm long × 24 sections (784 watts).

Selection will depend on space available. Over-rating is usual to allow for decrease in efficiency with age and effects of painting.

Height (mm)	Length (mm)	Sections	Watts (single)	Watts (double)
450	400	12	302	548
	500	15	378	686
	600	18	454	823
	700	21	529	960
	800	24	605	1097
	900	27	680	1234
	1000	30	756	1371
	1100	33	832	1508
	1200	36	907	1645
	1400	42	1058	1919
	1600	48	1210	2194
	1800	54	1361	2468
600	400	12	392	693
	500	15	490	866
	600	18	588	1039
	700	21	686	1212
	800	24	784	1386
	900	27	882	1559
	1000	30	980	1732
	1100	33	1078	1905
	1200	36	1176	2078
	1400	42	1372	2425
	1600	48	1568	2771
	1800	54	1764	3118

Note: Radiators are also manufactured in 300 and 700 mm standard heights.


Steel (inside diameter mm)
350
310
270
230
190
150
110
70
30
150
100
80
65
50
40
32
25
20
12
40
60
80
100
Copper (outside diameter mm)
560
520
480
440
400
360
320
280
240
200
160
120
80
40
133
108
76
67
54
42
35
28
22
15
10
8
50
70
90
110
130
Heat emission, watts per metre run
Temperature difference, pipe surface to air (K)
Note: Emission figures will vary slightly, depending on pipe quality and extent of painting

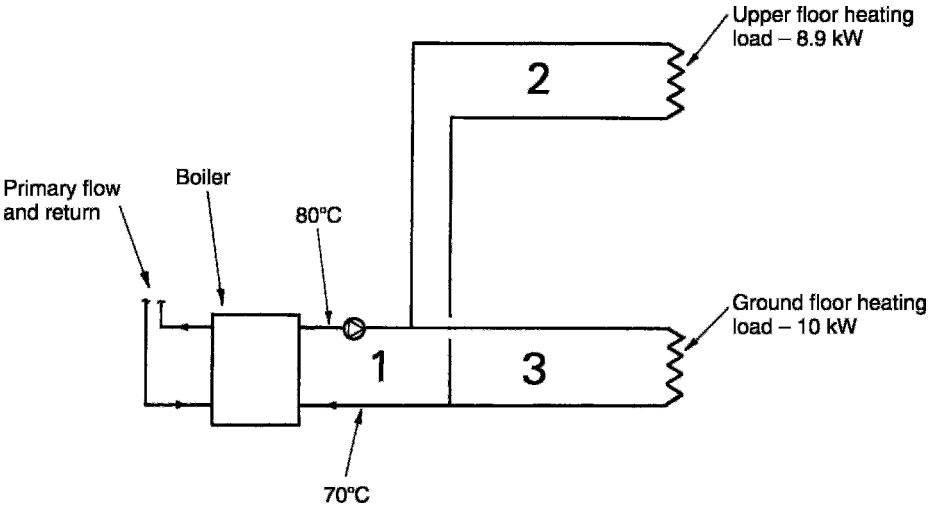
To determine the overall boiler rating, the requirement for hot water (see Part 2) is added to that necessary for heating. Heating requirements are established by summating the radiator specifications for each of the rooms. To this figure can be added a nominal percentage for pipework heat losses, the amount depending on the extent of insulation.

E.g. if the total radiator output in a house is 18 kW and an additional 5% is added for pipework losses, the total heating requirement is:

$$18 + (18 \times 5/100) = 18{\cdot}9 \text{ kW}.$$

Given the manufacturer's data of 80% boiler efficiency, the boiler gross heat input will be:

$$18{\cdot}9 \times 100/80 = 23{\cdot}63 \text{ kW}.$$



Pipes 1 – Heating flow and return at boiler

Pipes 2 – to upper floor

Pipes 3 – to ground floor

Schematic illustration, assuming a heating load of 8·9 kW on the upper floor and 10 kW on the ground floor, i.e. 18·9 kW total.

The size of pipework can be calculated for each sub-circuit and for the branches to each emitter. Unless emitters are very large, 15 mm o.d. copper tube or the equivalent is standard for connections to radiators in small bore installations. To illustrate the procedure, the drawing on the previous page allows for calculation of heating flow and return pipes at the boiler, and the supply pipes to each area of a house.

Pipes 1 supply the total heating requirement, 18·9 kW.
Pipes 2 supply the upper floor heating requirement, 8·9 kW.
Pipes 3 supply the lower floor heating requirement, 10 kW.

For each pair of pipes (flow and return) the mass flow rate is calculated from:

$$\text{kg/s} = \frac{\text{kW}}{\text{S.h.c.} \times \text{temp. diff. (flow} - \text{return)}}$$

Specific heat capacity (s.h.c.) can be taken as 4·2 kJ/kg K. The temperature differential between pumped heating flow and return will be about 10 K, i.e. 80°C – 70°C.

Therefore, the mass flow rate for:

$$\text{Pipes 1} = \frac{18{\cdot}9}{4{\cdot}2 \times 10} = 0{\cdot}45\ \text{kg/s}$$

$$\text{Pipes 2} = \frac{8{\cdot}9}{4{\cdot}2 \times 10} = 0{\cdot}21\ \text{kg/s}$$

$$\text{Pipes 3} = \frac{10{\cdot}0}{4{\cdot}2 \times 10} = 0{\cdot}24\ \text{kg/s}$$

Selecting a pumped water velocity of 0·8 m/s (see page 68) and copper tube, the design chart on page 132 indicates:

Pipes 1 = 35 mm o.d.
Pipes 2 = 22 mm o.d.
Pipes 3 = 22 mm o.d.

The specification for a pump is very much dependent on the total length of pipework, summated for each section within a system. In existing buildings this can be established by taking site measurements. For new buildings at design stage, estimates can be taken from the architects' working drawings. Actual pipe lengths plus an allowance for resistance due to bends, tees and other fittings (see page 29), provides an effective length of pipework for calculation purposes.

Using the previous example, given that pipes 1, 2 and 3 are 6 m, 10 m and 12 m effective lengths respectively, the design chart shown on page 132 can be used to determine resistance to water flow in each of the three sections shown:

Pressure drop in pipes 1 = 200 N/m^2 per metre (or pascals per metre).

Pressure drop in pipes 2 and 3 = 360 N/m^2 per metre (Pa per m).

Therefore: Pipes 1 @ 6 m × 200 Pa = 1200
Pipes 2 @ 10 m × 360 Pa = 3600
Pipes 3 @ 12 m × 360 Pa = 4320
9120 Pa or 9·12 kPa

From this calculation, the pump specification is 0·45 kg/s at 9·12 kPa.

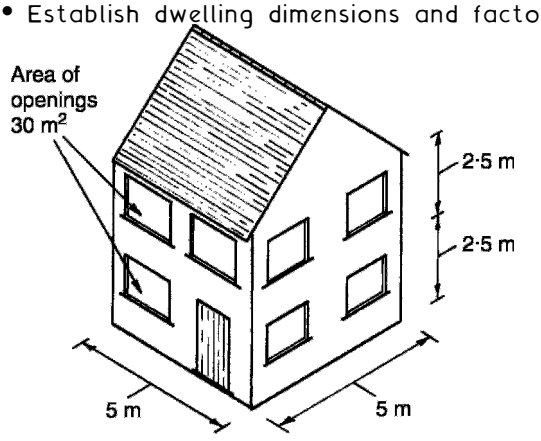
However, a higher figure for pump pressure will be necessary as the resistances in branch pipes to individual emitters will also need to be included. Pump selection is from manufacturer's pump performance charts similar to that shown on page 70.

Note: The smaller the pipe diameter, the greater the pressure drop or resistance to flow.

A simple and reasonably accurate estimate for determining boiler size.

Procedure –

- Establish dwelling dimensions and factor for location –



Detached house, location south east

UK location	Factor
North & Midlands	29
Scotland	28·5
South east	27
Wales	27
Northern Ireland	26·5
South west	25

- Approximate heat losses:

  Openings area (30 m^2) × Openings `U' value (2·00 ave.)* = 60 (A).

  Gross wall area (100 m^2) – Openings area (30 m^2) × Wall `U' value (0·35)* – 24·5 (B).

  Roof length (5 m) × Roof width (5 m) × Roof `U' value (0·16)* = 4 (C).

  Floor length (5 m) × Floor width (5 m) × Standard correction factor (0·7) = 17·5 (D).

  (For ceiling and floors in a mid-position flat, use zero where not exposed.)

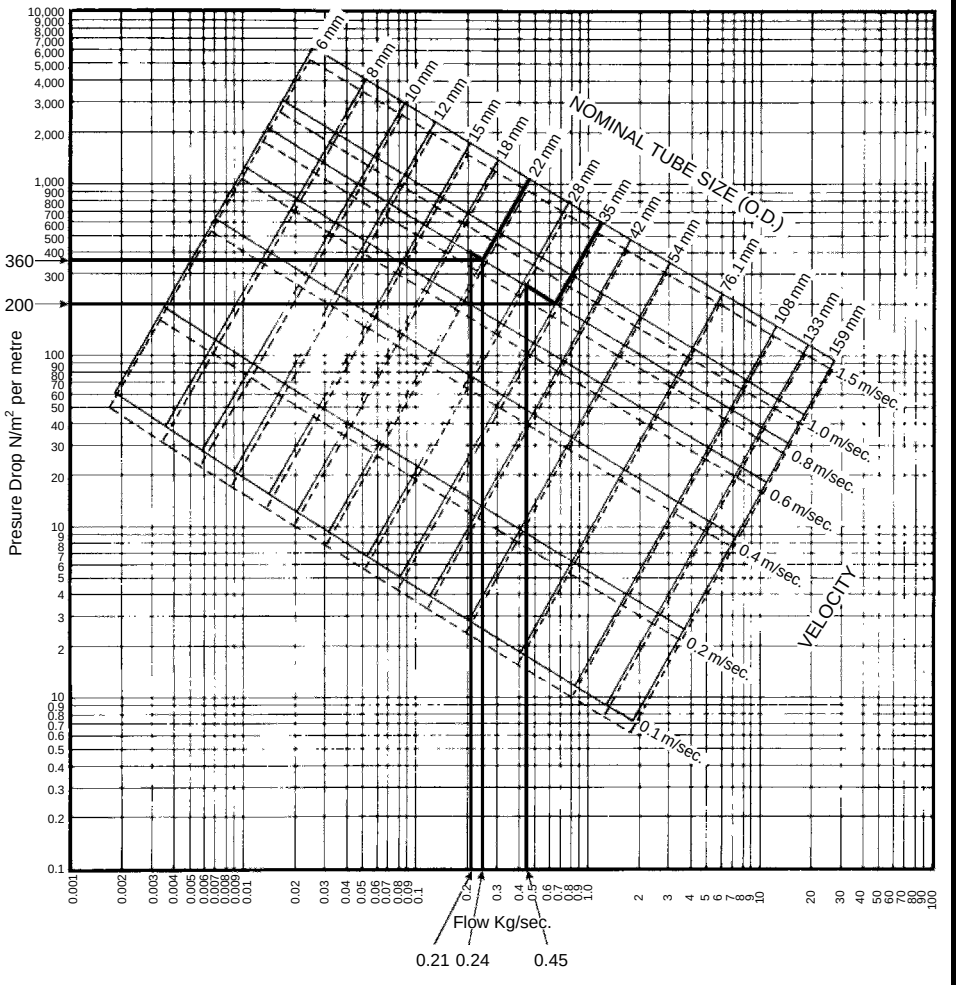
- Summate fabric losses: A + B + C + D = 106.
- Multiply by location factor: 106 × 27 = 2862 watts.
- Calculate ventilation losses:
  Floor area (25 m^2) × Room height (2·5 m) × No. of floors (2) = Volume (125 m^3 × Standard ventilation correction factor (0·25) × Location factor (27) = 843·75 watts.
- Boiler input (net) rating = 2862 + 843·75 + 2000 (watts for hot water) + calcs. for any extension to building = 5706 watts or 5·71 kW.

*See page 123 for `U' values.

Water Flow Resistance Through Copper Tube

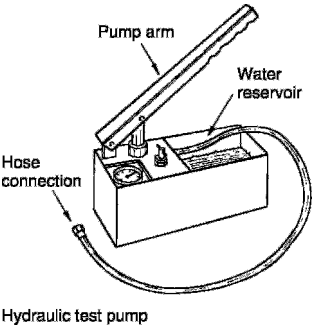
Unpressurised hot water (approx. 65°C)

Pressurised hot water (approx. 115°C)



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Testing medium – water is preferred to air, as water is virtually incompressible. Also, about 200 times more energy would be stored in compressed air at the same pressure and volume as for water. This could have a damaging effect on personnel and property if a component leaked or failed.
Where premises are particularly sensitive to water leakage, a low pressure air test can be undertaken before applying a hydraulic test.



Procedure

- Disconnect ancillary equipment that may not be designed to withstand test pressures, e.g. shower, boiler, etc. Manufacturer's data should be consulted.
- Check all system high points for location of air vents.
- Blank or plug any open ends including float valves. Close valves where sub-sections only are being tested.
- Open all valves in the enclosed section under test.
- Attach test pump to a convenient point.
- Start filling the system by pump priming and replenishing the pump water reservoir.
- Ventilate air from high points until water shows.
- When the system is full, raise the pressure as required.
- If pressure falls, check joints, valves, etc. for leakage.
- When the test is satisfied, ensure the appropriate documentation is signed.

Test requirements

- Rigid pipes – provide an internal water pressure at the lowest point in the system at 50% above normal operating pressure. This should hold for 1 hour. For example, 1 bar (10 m or 100 kPa) operating pressure requires a 1·5 bar (15 m or 150 kPa) test pressure.
- Plastic pipes – elastic by nature, will expand to some extent under pressure. Therefore the test procedure for rigid pipes is inappropriate. Either of the following tests, A or B is acceptable:

Test A – test pressure as for rigid pipes is applied and maintained for 30 minutes. After this time, pressure is reduced by one-third. For another 90 minutes the test is satisfied if there is no further reduction in pressure.
Test B – required test pressure is applied and maintained for 30 minutes. Test is satisfied if:

1. pressure drops <0·6 bar (60 kPa) after a further 30 minutes, and
2. pressure drops <0·2 bar (20 kPa) after a further 120 minutes, and
3. there is no visible leakage.

Application – underground and above ground systems of water pipework.
Ref. Water Supply (Water Fittings) Regulations, Schedule 2, Section 4, Paragraph 12.

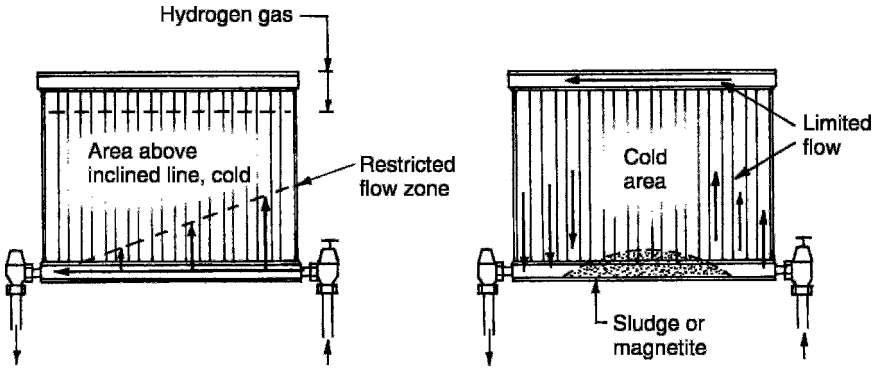
Boilers with a cast iron heat exchanger used with an indirect sealed system are unlikely to corrode. However, some electrolytic reaction between copper pipes and steel heat exchangers in boilers and pressed steel radiators is possible. Also, some corrosion of steel can occur where minute amounts of air enter the system. This may occur:

- Through undetected leakage at pipe joints
- From air present in solution
- From air dissolving into water contained in the feed and expansion cistern.

The initial indication of internal corrosion is one or more radiators failing to get hot and a need for frequent 'bleeding' through the air valve. Corrosion produces hydrogen gas. This may be detected by holding a lighted taper to the draught escaping at the air valve. Caution should be observed when effecting this test and if the taper is seen to burn with a blue flame, hydrogen is present. Air will not burn.

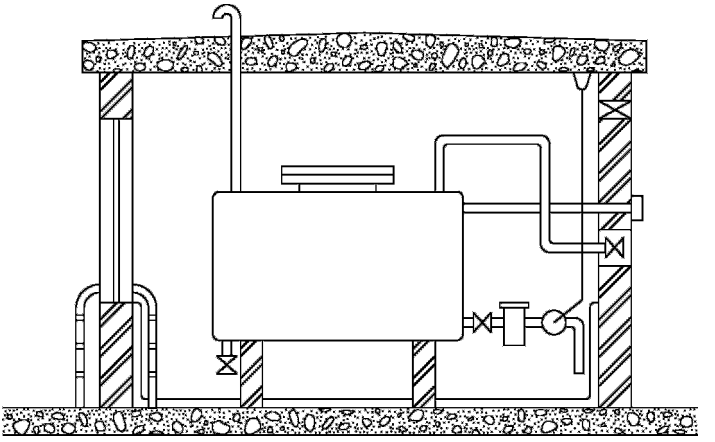
Another characteristic of corrosion is black sludge accumulating in the bottom of radiators. This is known as magnetite and it may also obstruct circulating pipes. Magnetite is the metallic breakdown of steel radiator walls. In addition to blockage and corrosion, magnetite is drawn to the magnetic field of the circulating pump where its abrasive presence may cause the impellor to fail.

Corrosion in heating systems can be prevented or at least considerably reduced, by introducing a proprietary inhibitor to the feed and expansion cistern as the system is filled. With sealed systems the inhibitor can be introduced with a funnel and hose temporarily connected to a high level radiator.



Internal corrosion of radiators

4 FUEL CHARACTERISTICS AND STORAGE



FUELS – FACTORS AFFECTING CHOICE
SOLID FUEL – PROPERTIES AND STORAGE
DOMESTIC SOLID FUEL BOILERS
SOLID FUEL – FLUES
OIL – PROPERTIES
OIL – STORAGE
OIL-FIRED BURNERS
OIL – FLUES
NATURAL GAS PROPERTIES
LPG – PROPERTIES AND STORAGE
ELECTRIC BOILER
ELECTRICITY – ELECTRODE BOILER

One of the most important considerations for providing an effective means of heating water is selection of an appropriate fuel. Choice and selection is a relatively new concept, as until the 1960s mains gas was rarely available outside of large towns and cities. Also, the cost of fuel oil was prohibitive for most people. The majority of domestic premises were heated by solid fuel for open fires with a back boiler for hot water. Solid fuel boilers for hot water and central heating were available, but the associated technology of pumps and thermostatic controls were rudimentary by today's standards. Systems of the time required considerable attention, not least frequent replenishment of fuel and disposal of ash. The post-1960s era led to much higher expectations in domestic comfort and convenience standards. This coincided with considerable developments in fuel burning appliances to complement the availability of new gas and oil resources from off-shore sources.

Practical factors and amenity issues may still limit or simplify choice, e.g. in some areas mains gas is not available and some buildings may have very limited space for fuel storage, or none at all. Personal preference as a result of previous experience, sales presentations or promotions may also have an important influence.

Amenity factors:

Facility to control the fuel, i.e. response to thermostatic and programmed automation.
Space for fuel storage.
Space for a boiler or special facilities to accommodate it.
Accessibility for fuel delivery.
Planning issues: chimneys and flue arrangements.
Location – conformity with Clean Air Act and exhaust emissions.
Maintenance requirements and after-care programme.
Availability.

Economic factors:

Capital cost of installation.
Cost of fuel storage facility.
Cost of special equipment.
Cost of equipment accommodation/plant room.
Cost of constructing a service area/access road.
Fuel costs – current and projected.
Flexibility of boiler, i.e. facility to change to another fuel.

Appropriate as logs of wood or as a coal product for open fires, stoves and boilers. A considerable amount of space is required for storage and manual handling is very much a feature. Arrangements must be made for fuel deliveries and disposal of ashes. Although the combustion efficiency is generally lower than oil or gas, some degree of automation is possible with the more efficient slow burning anthracites. Domestic boilers have several days' burning potential by gravity fed integral hopper. Instantaneous control is not possible and skilful operation is required to maintain boilers at low output.

Chimney construction and flue requirements must comply with Approved Document J to the Building Regulations. These are generally much larger and more visual than that required for use with other fuels. The sulphur content from burnt coal products is corrosive to many materials, therefore flue construction must not contain stainless steel linings or other materials which could be affected. The sulphur also contributes to atmospheric pollution.

Properties:

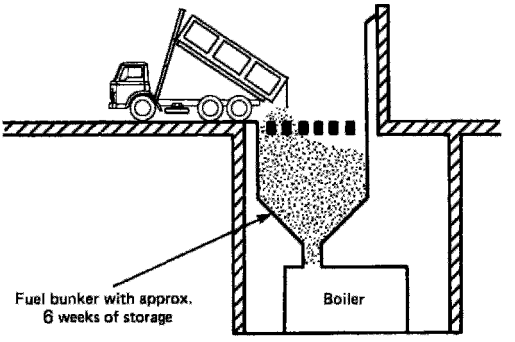
Fuel type	Calorific value MJ/kg	Sulphur content %	Bulk density* kg/m^3
Anthracite†	33	1.0	750–800
Coking coal	30	1.0	600–800
Dry steam coal†	30	1.1	
Strong caking coal	29	1.9	
Medium caking coal	27	1.9	
Weak caking coal	26	1.9	
Non-caking coal	24	1.8	
Manufactured coke†	28	N/A	400–500
Wood	19	N/A	300–800

Notes:

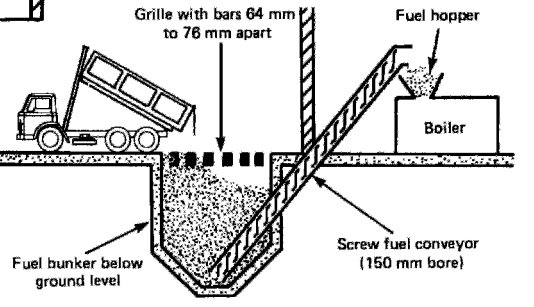
* Variation depending on granular size. Unit size and species for wood.

† Smokeless fuels.

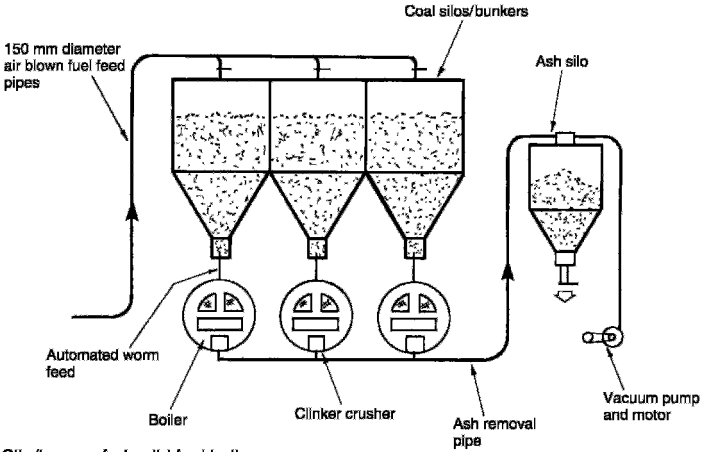
When solid fuel is to be used it is essential to consider accommodation for fuel storage and facilities available. For domestic and small buildings where requirements are minimal, a brick or concrete bunker of nominal size is adequate. Industrial and commercial premises will require a fuel bunker or hopper above the boiler to reduce manual handling. Motorised feed mechanisms can be used to regulate fuel delivery to the boilers and vacuum pumps can effect extraction of ashes.



Solid fuel boiler in basement or sub-basement



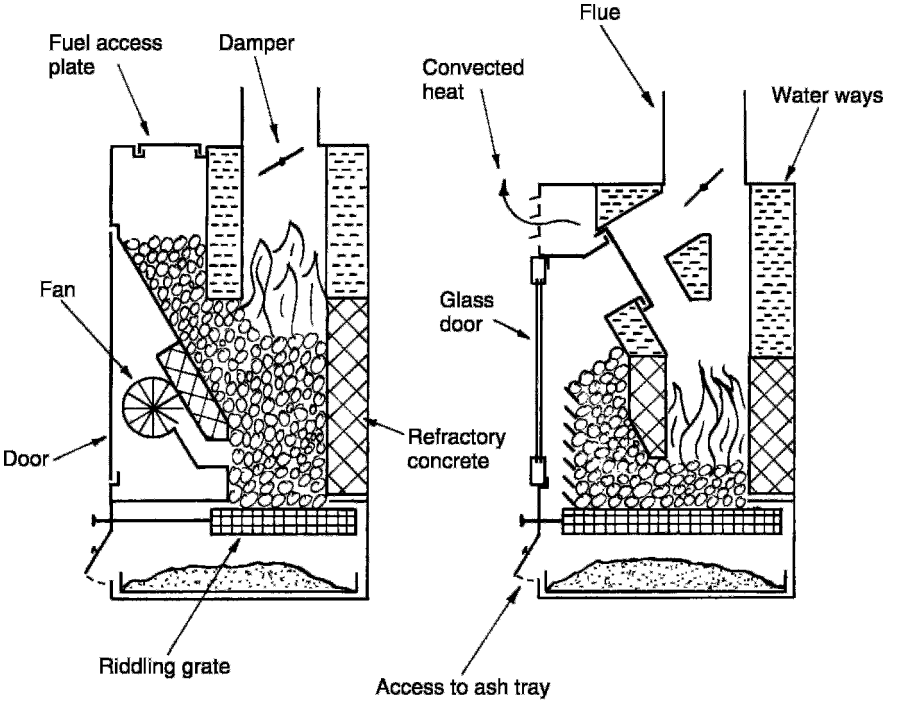
Solid fuel boiler at ground level



Silo/hopper-fed solid fuel boilers

Back boilers situated behind a fireplace are limited to providing room heat from the fire, hot water by gravity circulation to a storage cylinder and perhaps a couple of radiators or a towel rail off the primary flow and return. They were standard installations in many 1930s houses, but are now virtually obsolete. The combined room heater and boiler shown below is an improvement, having an enclosed fire and a convected outlet to heat the room in which it is installed. The water jacket is of sufficient capacity to provide hot water for storage and for several radiators. These appliances will require re-stoking every few hours.

Independent boilers are free standing, automatically fed by hopper and require only a flue. A chimney structure is not necessary, provided the flue satisfies Approved Document J to the Building Regulations. The integral fuel store contains small granules or 'peas' of anthracite and will require minimal attention with a burning capacity of several days. Automatic control is by thermostat in the water way to regulate a fan assisted air supply for complete combustion. These boilers are designed with sufficient capacity to provide hot water and central heating for most domestic situations.

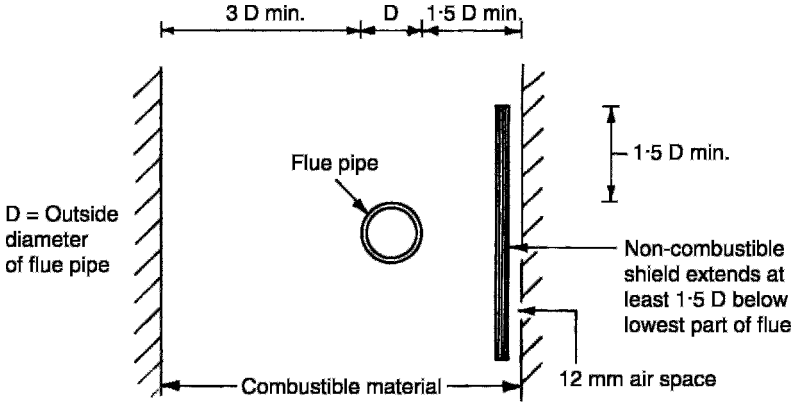


Flue pipes may be used to connect a solid fuel burning appliance to a chimney. They must not pass through a roof space, partition, internal wall or floor. Acceptable connecting flue pipe materials are:

- Cast iron to BS 41: Specification for cast iron spigot and socket flue or smoke pipes and fittings.
- Mild steel with a flue wall thickness of at least 3 mm, complying with BS 1449-1: Steel plate, sheet and strip.
- Stainless steel with a flue wall thickness of at least 1 mm, complying with BS EN 10088-1: Stainless steels, grades 1·4401, 1·4404, 1·4432 or 1·4436.
- Vitreous enamelled steel pipe complying with BS 6999: Specification for vitreous-enamelled low-carbon-steel flue pipes, other components and accessories for solid-fuel-burning appliances with a maximum rated output of 45 kW.

All spigot and socket jointed pipes to be fitted socket uppermost and sealed with a non-combustible rope and fire cement or proprietory equivalent.

Any combustible material used in construction must be at least 200 mm from the inside surface of the flue. Where any metal fixings are in contact with combustible materials they must be at least 50 mm from the inside surface of a flue.



Other requirements for closeness of combustible material

Flue outlets must be above the roof line to effect clear, unhindered dispersal of combustion products without creating a fire hazard. See `Open Fire Places and Flues´ in the *Building Construction Handbook*.

Flue length and height must be sufficient to encourage adequate draught and efflux (discharge) velocity at the terminal, with regard to limiting the possibility of condensation occurring in the flue. Flue gases cool relative to the flue pipe and surrounding structure temperature, until dew point of water occurs at about 60°C. Flue linings must therefore be impervious and resistant to corrosion. If condensation is a problem, a small diameter vertical drain can be located at the base of the flue.

Flue direction should be straight and vertical wherever possible. Horizontal runs are to be avoided. If the appliance has a back outlet connection an exception is made, but the horizontal flue length must not exceed 150 mm before connecting to a chimney or vertical flue. Bends should not exceed 45°C to the vertical to maintain a natural draught and to ease cleaning.

Flue size is never less than that provided on the appliance outlet.

Boiler, cooker or stove	Min. flue size
<20 kW rated output	125 mm dia. or square/rectangular equivalent area, with a minimum dimension of 100 mm in straight flues and 125 mm in bends
20–30 kW rated output	150 mm dia. or square/rectangular equivalent area, with a minimum dimension of 125 mm
30–50 kW rated output	175 mm dia. or square/rectangular equivalent area, with a minimum dimension of 150 mm

Flue size in chimneys varies between 125 and 200 mm diameter (or square/rectangular equivalent) depending on application and appliance rating.

Refs. Building Regulations, Approved Document J: Combustion appliances and fuel storage systems. Sections 2.4 to 2.7.

Air Supply to Solid Fuel Burning Appliances

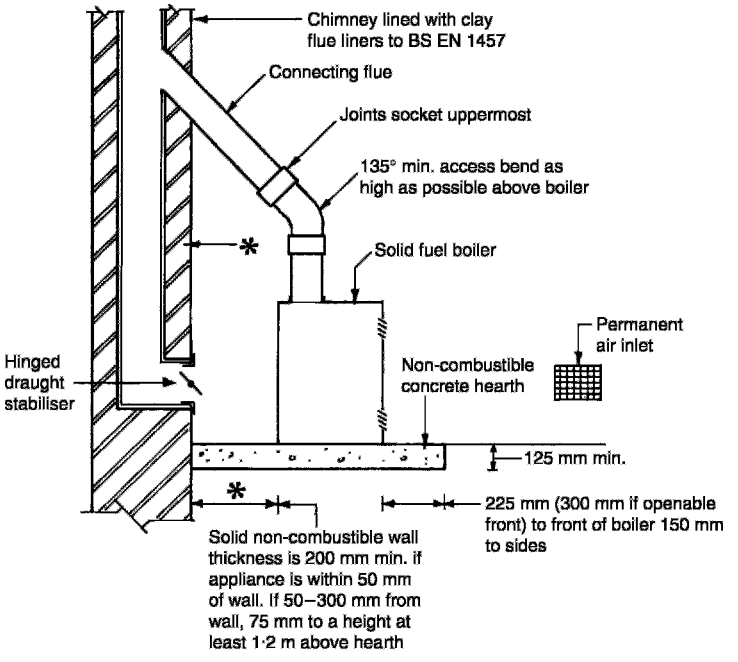
Appliances require air (oxygen) for efficient combustion of fuel. This requires purpose-made ventilation openings in the structure, size depending on the appliance type and rating.

Appliance type	Permanently open ventilation
Boiler, cooker or stove with a flue draught stabiliser	300 mm^2/kW for the first 5 kW of rated output, 850 mm^2/kW thereafter
As above, without a flue draught stabiliser	550 mm^2/kW of rated output above 5 kW

E.g. A 20 kW boiler attached to a draught stabilised flue.

$(300 \times 5) + (850 \times 15) = 14250\ mm^2$

Taking the square root of 14250, indicates an open draught of at least 120 × 120 mm.



Solid fuel boiler and flue connections

Ref. Building Regulations, Approved Document J: Combustion appliances and fuel storage systems. Sections 2.1 to 2.3
BS 5854: Code of practice for flues and flue structures in buildings.

Fuel for boilers is manufactured by processing crude oil. The crude is distilled and condensed to produce a variety of commercial brands including gasolenes, kerosenes and gas oils. Distillates are blended to create several grades suitable as boiler fuels.

Kerosene (known commercially as Class C2) is an unblended relatively expensive light distillate suitable for domestic vaporising or atomising oil-fired boilers. Gas oil (Class D) is a heavier and less expensive distillate suitable for larger atomising burners in domestic and industrial applications. Fuel oils (Classes E, F, G and H) are a blend of residual oils with distillates that are considerably cheaper than the other classes. They are also heavier and generally require storage and handling plant with heating facilities. They require pre-heating before pumping and atomising for burning. These oils are limited to large-scale plant that has high level chimneys to discharge the pollutants and dirty flue gases characteristic of their high sulphur content.

Characteristics:

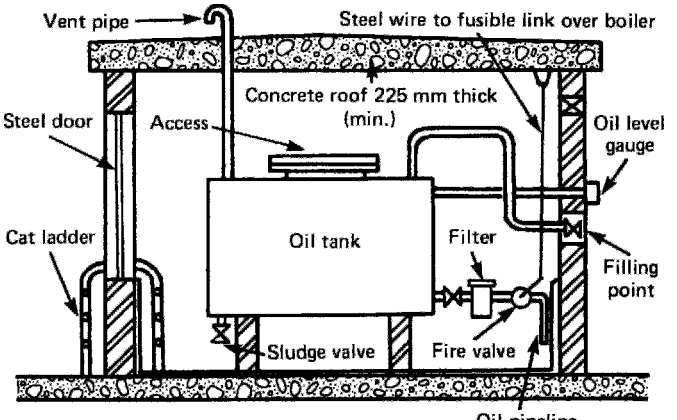
	Kerosene	Gas oil	Residue-containing burner fuels			
Class	C2	D	E	F	G	H
Density	790	840	930	950	970	990 kg/m^3
Flash point	38	56	66	66	66	66°C
Calorific value	46·4	45·5	43·4	42·9	42·5	42·2 MJ/kg
Sulphur content	0·2	0·2	3·5	3·5	3·5	3·5%
Kinematic viscosity	2·0	5·5	8·2	20	40	56*
Minimum storage temp.	N/A	N/A	10	25	40	45°C

Note: * Class C2 and D at 40°C.
Classes E, F, G and H at 100°C.

Ref: BS 2869: Fuel oils for agricultural, domestic and industrial engines and boilers. Specification.

An oil storage tank may be located externally. Unless the tank is underground or provided with a fire resistant barrier, it must be sited at least 1.8 m from the building. A plant room may be used if constructed in accordance with the local fire regulations. It must be built of fire resistant materials, with the base and walls to flood level rendered with cement mortar to contain all the oil in the tank plus 10% in the event of a leakage. Where the oil storage room is within a building, it should be totally enclosed with walls and floors of at least 4 hours' fire resistance.

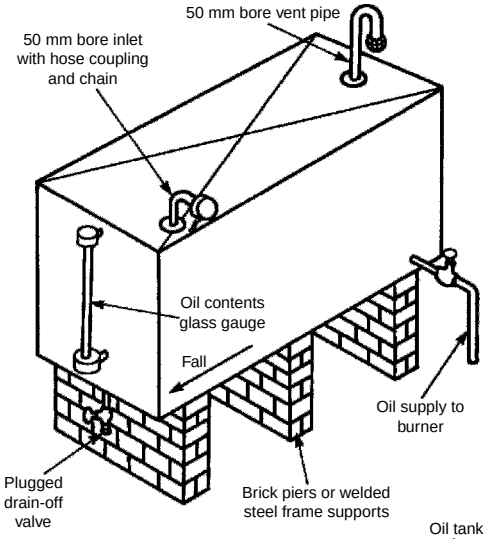
As a guide to tank capacity, it should equate to the normal delivery plus 2 weeks' supply at maximum consumption or 3 weeks' average supply – take the greater. Supply pipelines can be as little as 8 or 10 mm o.d. annealed copper in coils to eliminate jointing. They can also be of steel for larger installations. Industrial supplies have the pipes insulated and trace wired to keep the oil warm. The tank should be elevated to provide at least 0·5 m head to effect the level controller or metering valve. If this is impractical, the supply can be pumped. The maximum head is 4 m.



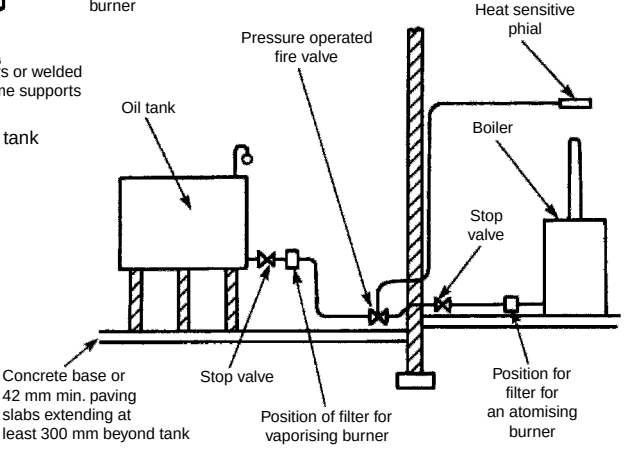
Oil fuel storage room

Refs: Environment Agency publication PPG 2: Above ground oil storage tanks.
BS 5410-1: Code of practice for oil firing – Installations up to 45 kW output capacity for space heating and hot water supply purposes.

An oil storage tank is usually rectangular with a raised top designed to shed water. Tanks for domestic application have a standard capacity of 2275 litres (2·275 m^3) for economic deliveries of 2 m^3. A vertical sight glass attached to the side provides for easy visual indication of the level. Tanks are made from ungalvanised welded carbon steel or sectional pressed ungalvanised carbon steel with internal strutting to prevent deformity when full. They are also produced in plastic. Brick piers or a structural steel framework is used to raise the tank above the ground. This is necessary to avoid corrosion from ground contact and to create sufficient head or pressure (0·5 m min.) from the outlet to the burner equipment. Location must be within 30 m of the oil tanker vehicle access point, otherwise an extended fill line must be provided.



Installation of outside oil storage tank



Oil supply to burner

Bund – generally defined as an embankment or structure used for containment or retention purposes. In the context of oil storage and the interests of reducing the significance and expense of potential environmental damage due to oil seepage into the ground, a bund must be constructed around storage vessels. This is a precautionary measure to retain oil in the event of a leakage.

Objective – to prevent oil percolating into the ground surrounding an oil tank and contaminating a watercourse.

Application – above ground oil storage in excess of 200 litres capacity for industrial, commercial and institutional (residential and non-residential) premises.

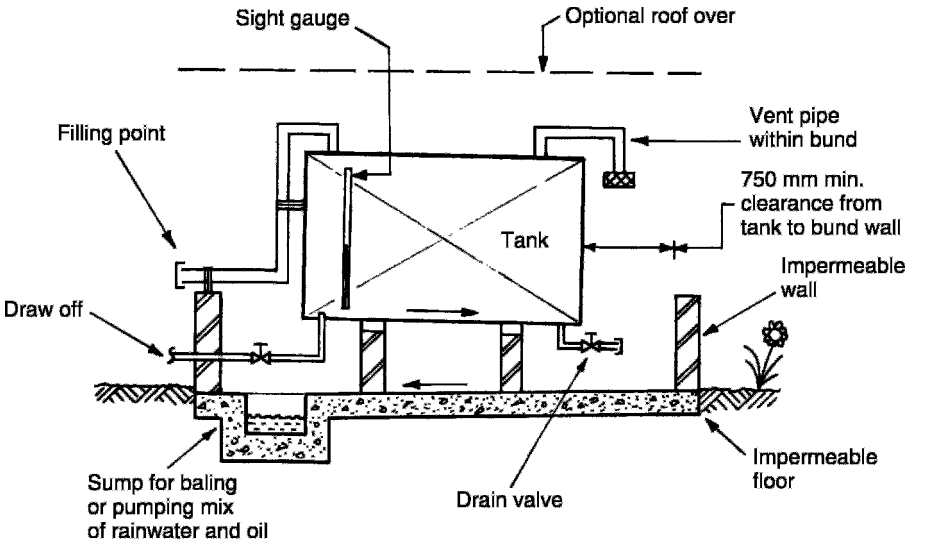
Location – <10 m from a watercourse (river, stream, land drain, etc.).

<50 m from a well or borehole.

Exemption – for the time being, private dwellings with less than 3500 litres storage capacity used for domestic heating only.

Construction – of impermeable material, e.g. engineering brick wall and dense concrete base.

Capacity – minimum 110% of the storage tank volume.



Bunded oil tank

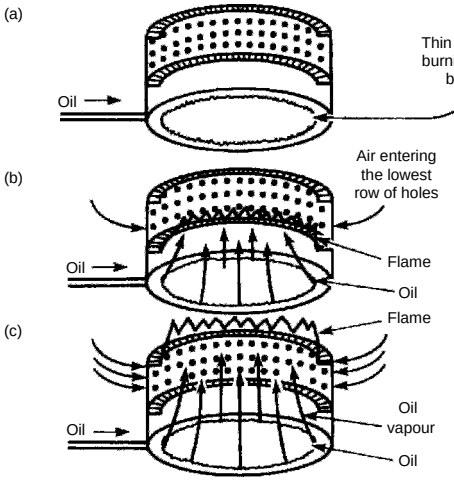
Refs. Control of Pollution (Oil Storage) (England) Regulations.

Water Resources Act, Sections 92 and 219.

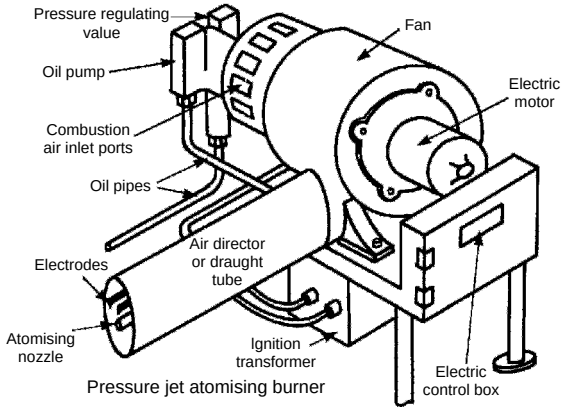
There are two types of oil burner: 1. vaporising; 2. atomising.

1. The natural draught vaporising burner consists of a cylindrical pot which is fed with oil at its base from a constant oil level controller. When the burner is lit, a thin film of oil burns in the bottom. Heat is generated and the oil is vaporised. When the vapour comes into contact with air entering the lowest holes, it mixes with the air and ignites. At full firing rate more air and oil mix until a flame burns out of the top of the burner.

2. The pressure jet atomising burner has an atomising nozzle. This produces a fine spray of oil which is mixed with air forced into the burner by a fan. Ignition electrodes produce a spark to fire this air/ oil mixture.



Natural draught pot vaporising burner

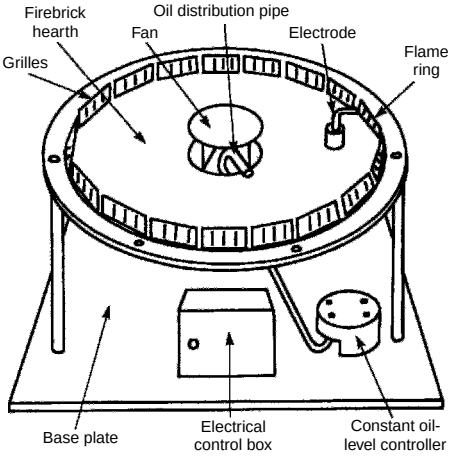


Pressure jet atomising burner

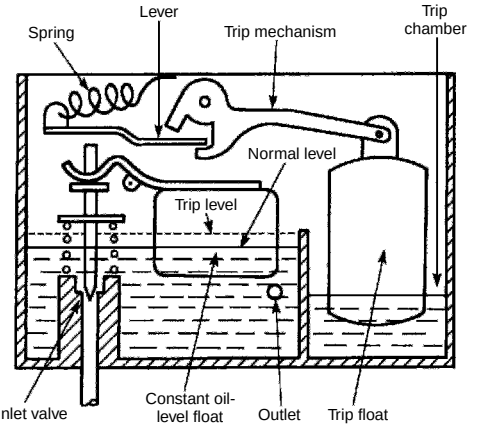
Wall-flame Oil Burner/Oil-level Controller

The wall-flame burner consists of a steel base plate securing a centrally placed electric motor. The armature of this motor is wound on a hollow metal shroud which dips into an oil well. A constant oil-level controller feeds the well, just covering the edge of the shroud. The shroud is circular with its internal diameter increasing towards the top, from which two holes connect with a pair of oil pipes. When the motor is engaged, oil is drawn up to the pipes and thrown onto the flame ring. Simultaneously, air is forced onto the rings by the fan. This air/oil mixture is ignited by the electrodes.

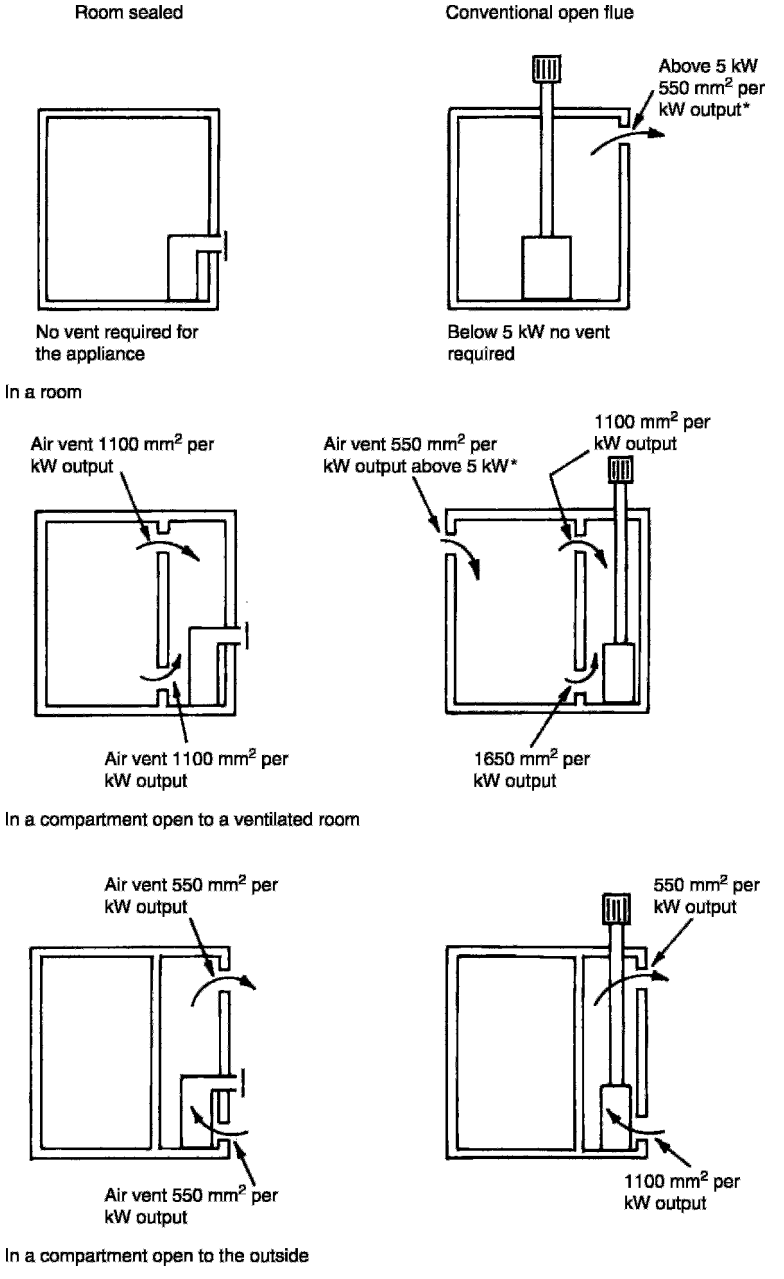
The constant oil-level controller is used to feed vaporising burners. If the inlet valve fails to close, oil flows into the trip chamber. The trip float rises and operates the trip mechanism, thus closing the valve.



Wall-flame rotary vaporising burner



Constant oil-level controller

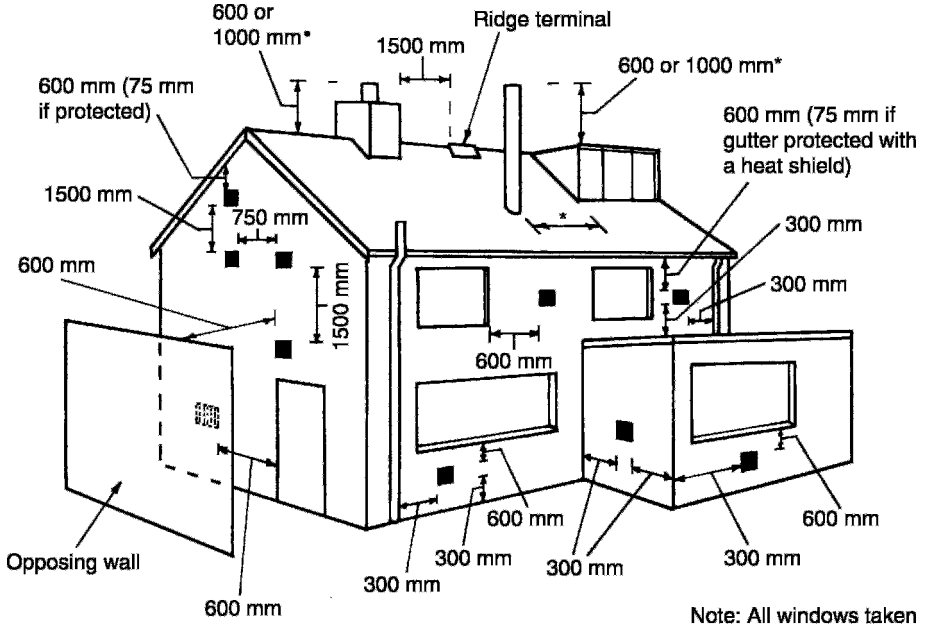


* Ventilation should be increased by an additional 550 mm² per kW output where the appliance has a draught break, i.e. a draught stabiliser or draught diverter.

Outlets from flues serving oil-fired appliances, rated up to 45 kW output, must be carefully located to ensure:

- natural draught for fuel combustion
- efficient and safe dispersal of combusted fuel products
- adequate air intake if combined with a balanced flue.

In conjunction with the air inlet provisions shown on the previous page, the following guidance should ensure efficient combustion and burnt fuel gas dispersal.



Flue terminal positions (minimum dimensions)

Ref. Building Regulations, Approved Document J: Combustion appliances and fuel storage systems. Section 4.

The following guidance provides minimum acceptable dimensions with regard to appliance efficiency, personnel and fire safety. The listing should be read with the illustration on the previous page. Local conditions such as wind patterns may also influence location of terminals. Flue terminal guards may be used as a protective barrier where direct contact could occur.

Location of terminal	Pressure jet atomising burner	Vaporising burner
Directly under an openable window or a ventilator	600	Not to be used in these situations
Horizontally to an openable window or a ventilator	600	
Under eaves, guttering or drainage pipework	600	
As above, with a 750 mm wide heat shield	75	
Horizontally from vertical drain or discharge pipes	300	
Horizontally from internal or external corners	300	
Horizontally from a boundary	300	
Above ground or balcony	300	
From an opposing wall or other surface	600	
Opposite another terminal	1200	
Vertically from a terminal on the same wall	1500	
Horizontally from a terminal on the same wall	750	
From a ridge terminal to a vertical structure	1500	
Above the intersection with a roof	600	1000 •
Horizontally to a vertical structure	750	2300 *
Above a vertical structure <750 mm (pressure jet burner) or <2300 mm (vaporising burner) horizontally from a terminal	600	1000 *

Notes:
Dimensions in mm.
No terminal to be within 300 mm of combustible material.
Where a vaporising burner is used, the terminal should be at least 2300 mm horizontally from a roof.
See previous page for • and *.

UK gas supplies originate from decaying organic matter found at depths up to 3 km below the North Sea. Extract is by drilling rigs and pipelines to the shore. On shore it is pressurised to about 5 kPa throughout a national pipe network.

Properties of natural gas:

Methane	89·5%
Ethane	4·5%
Propane	1·0%
Pentane	0·5%
Butane	0·5%
Nitrogen	3·5%
Carbon dioxide	0·5%

The composition shown will vary slightly according to source location. All the gases above are combustible except for nitrogen. Natural gas is not toxic, but incomplete combustion will produce carbon monoxide, hence the importance of correct burner and flue installations. A distinctive odour is added to the gas, as in its natural state it has no detectable smell. Natural gas is lighter than air with a specific gravity of about 0.6, relative to 1.0 for air.

Characteristics:

Calorific value	36–40 MJ/m^3
Specific gravity	0·5–0·7
Wobbe No.	approx. 50%
Sulphur	approx. 20 mg/m^3

Note: The Wobbe No. is sometimes used to represent the thermal input of an appliance for a given pressure and burner orifice. It is calculated from:

$$\frac{\text{Calorific value}}{\sqrt{\text{Specific gravity}}} \quad \text{e.g.} \quad \frac{40}{\sqrt{0{\cdot}6}} = 51\%$$

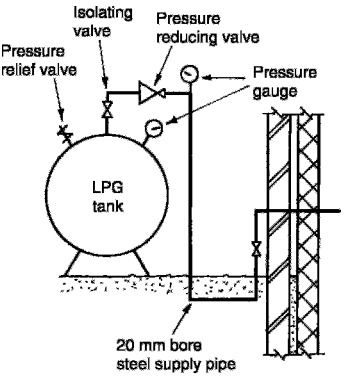
Natural gas has many advantages over other fuels, including: clean and efficient burning, no storage, less maintenance, relatively economic and a minimum of ancillaries.

Families of gases:

Family	Type of gas	Wobbe No. (%)
1	Manufactured, e.g. coal gas	22–30
2	Natural	39–55
3	Liquid petroleum	73–87

LPGs are a by-product of the oil refining process. They are also found naturally in the north sea and other oil fields. These gases are liquefied in containers to about 1/200 of their volume as a gas by application of moderate pressure for convenience in transportation and storage. They are marketed as two grades, propane and butane, under various brand names. Both grades are heavier than air, therefore periphery walls around storage containers are unacceptable. If there were a leakage, the vapour would be trapped at low level and be unable to disperse. Calorific values differ considerably from natural gas, therefore appliances are not interchangeable. Siting of storage vessels should be away from buildings, boundaries and fixed sources of ignition as a precaution in event of fire.

Storage tank capacity (m^3)	Min. distance from building or boundary (m)
<0·45	–
0·45–2·25	3·0
2·25–9·00	7·5
>9·00	15·0



Containerised LPG

Characteristics:

Propane:

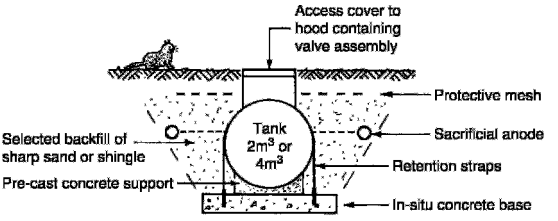
Calorific value	96 MJ/m^3 (dry) 50 MJ/kg
Specific gravity	1·4–1·55
Sulphur content	0·02%
Air for combustion	24 m^3 per m^3 of gas

Butane:

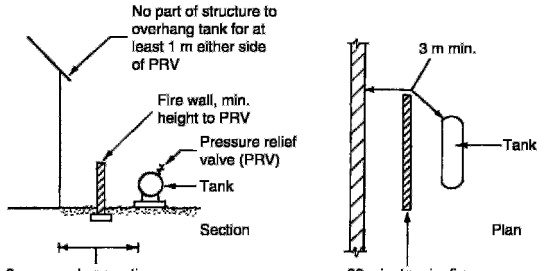
Calorific value	122 MJ/m^3 (dry) 50 MJ/kg
Specific gravity	1·9–2·1
Sulphur content	0·02%
Air for combustion	30 m^3 per m^3 of gas

Refs. Building Regulations, Approved Document J, Section 5: Provisions for liquid fuel storage and supply.
BS 5588-0: Fire precautions in the design, construction and use of buildings. Guide to fire safety codes of practice for particular premises/applications.

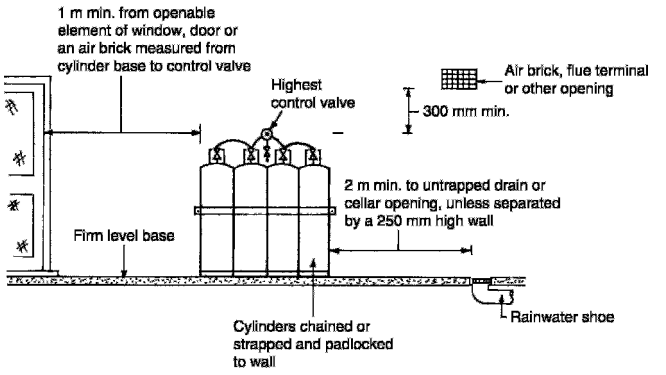
LPG may be stored below or above ground in tanks and above ground in cylinders. Tanks are provided in a standard volume of 2 or 4 m^3 (2000 or 4000 litres capacity), sited no more than 25 m from a road or driveway for hose connection to the replenishment tanker. Cylinder location is less critical, these are in a set of 4 (47 kg each) for use two at a time, with a simple change over facility as required. Tanks and cylinders must not obstruct exit routes. Where a tank is located in the ground, it is fitted with sacrificial anodes to prevent decay by electrolytic activity.



Below ground installation (section)



Storage tank location

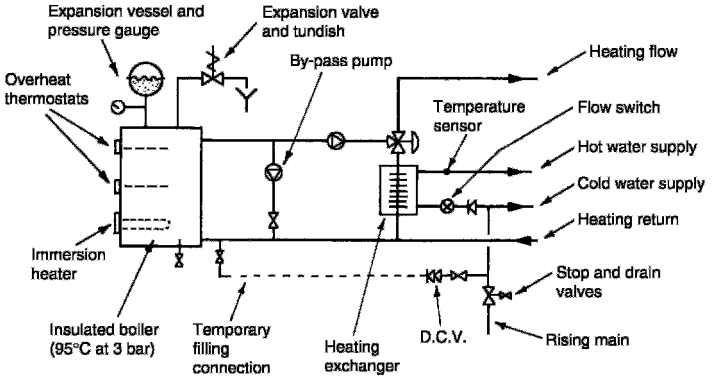


LPG cylinders

Electrically powered boilers have the advantage of no maintenance, no flue, over 99% efficiency* and no direct discharge of noxious gases.

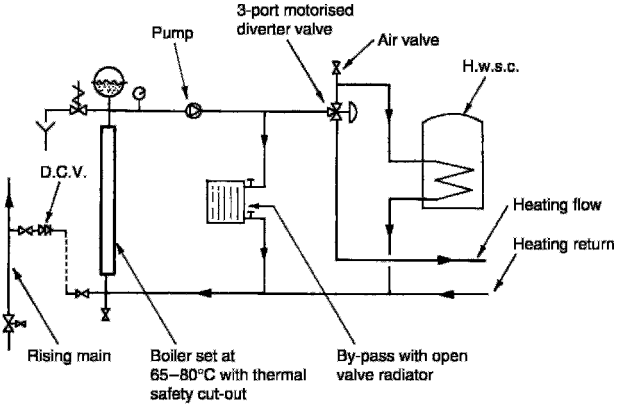
* Energy loss is at the power station where conversion of fuel energy into electricity can be as little as 50% efficient.

Primary thermal store (>15 litres capacity) – these use off-peak electricity, normally through a 3 kW immersion heater as an economic means for creating a store of hot water. They have the option of supplementary power at standard tariff through higher rated immersion heaters to satisfy greater demand.



Primary store boiler

Instantaneous (<15 litres capacity) – these low water content, high powered (6–12 kW) units provide direct heat energy at standard tariff in response to programmed demand. They are very compact, generally about 100 mm square × 1 m in height. Integral controls include a thermal safety cut-out and 'soft' switching to regulate power supply as the unit is engaged.

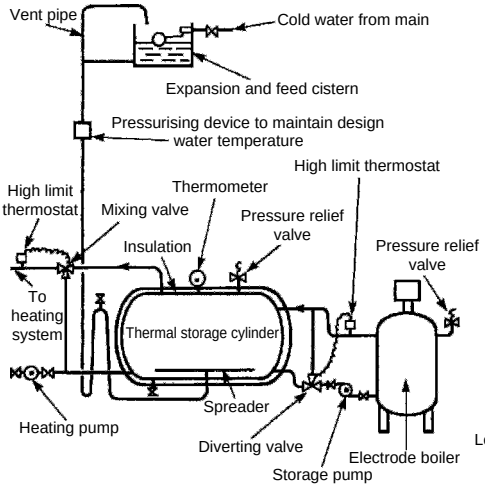


Instantaneous boiler

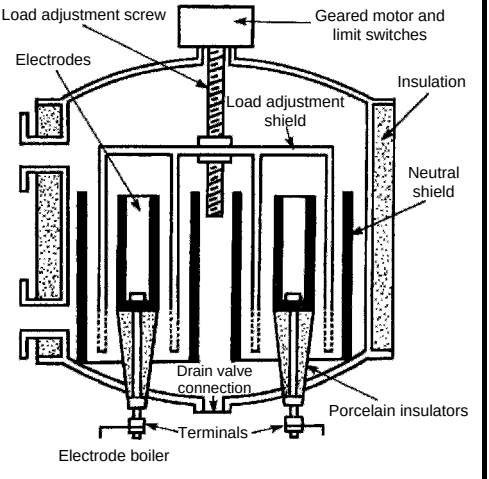
Electricity can be used directly in convectors, fan heaters, element fires, etc., or indirectly as shown below as hot water thermal storage heating. It is an alternative use of off-peak electricity to storage in concrete floors or thermal block space heaters and has the advantage of more effective thermostatic control.

Electricity is converted to heat energy in water by an electrode boiler and stored in a pressurised insulated cylinder at about 180°C. The water is circulated by a pump programmed for daytime use to heat emitters in the building. Careful design of the storage vessel is essential to maintain sufficient thermal capacity for the heating requirements. An assessment of demand will need to be presented to the supply authority and a reduced rate of electricity tariff may be negotiated, possibly between 1900 and 0700 hours.

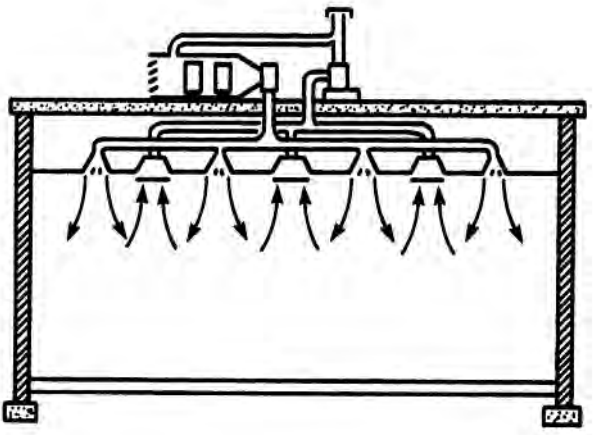
Calorific value of electricity . . . . . 3·6 MJ/kWh



Heating system using water



5 VENTILATION SYSTEMS



VENTILATION REQUIREMENTS
GUIDE TO VENTILATION RATES
DOMESTIC ACCOMMODATION
NON-DOMESTIC BUILDINGS
NATURAL VENTILATION
PASSIVE STACK VENTILATION
MECHANICAL VENTILATION
DUCTING-PROFILE AND MATERIALS
TYPES OF FAN
FAN LAWS
SOUND ATTENUATION IN DUCTWORK
AIR FILTERS
LOW VELOCITY AIR FLOW IN DUCTS
AIR DIFFUSION
VENTILATION DESIGN
DUCT SIZING
RESISTANCES TO AIR FLOW

Ventilation Requirements

Ventilation – a means of changing the air in an enclosed space to:

- Provide fresh air for respiration – approx. 0·1 to 0·2 l/s per person.
- Preserve the correct level of oxygen in the air – approx. 21%.
- Control carbon dioxide content to no more than 0·1%. Concentrations above 2% are unacceptable as carbon dioxide is poisonous to humans and can be fatal.
- Control moisture – relative humidity of 30% to 70% is acceptable.
- Remove excess heat from machinery, people, lighting, etc.
- Dispose of odours, smoke, dust and other atmospheric contaminants.
- Relieve stagnation and provide a sense of freshness – air movement of 0·15 to 0·5 m/s is adequate.

Measures for control:

Health and Safety at Work, etc. Act.
The Factories Act.
Offices, Shops and Railway Premises Act.
Building Regulations, Approved Document F – Ventilation.
BS 5925: Code of practice for ventilation principles and designing for natural ventilation.

The statutes provide the Health and Safety Executive with authority to ensure buildings have suitably controlled internal environments. The Building Regulations and the British Standard provide measures for application.

Requirements for an acceptable amount of fresh air supply in buildings will vary depending on the nature of occupation and activity. As a guide, between 10 l/s of outdoor air supply per person can be applied between the extremes of a non-smoking environment, to an extract air rate of 36 l/s per person in a room dedicated specifically for smokers. Converting this to m^3/h (divide by 1000, multiply by 3600), equates to 36 to 130 m^3/h per person.

Air changes per hour or ventilation rate is the preferred criteria for system design. This is calculated by dividing the quantity of air by the room volume and multiplying by the occupancy.

E.g. 50 m^3/h, 100 m^3 office for five persons: $50/100 \times 5 = 2{\cdot}5$ a/c per h.

Room/building/accommodation	Air changes per hour
Assembly/entrance halls	3–6
Bathrooms (public)	6*
Boiler plant rooms	10–30†
Canteens	8–12
Cinema/theatre	6–10
Classrooms	3–4
Dance halls	10–12
Dining hall/restaurants	10–15
Domestic habitable rooms	approx. 1*
Factories/garages/industrial units	6–10
Factories – fabric processing	10–20
Factories (open plan/spacious)	1–4
Factories with unhealthy fumes	20–30
Foundries	10–15
Hospital wards	6–10
Hospital operating theatres	10–20
Kitchens (commercial)	20–60*
Laboratories	6–12
Laundries	10–15
Lavatories (public)	6–12*
Libraries	2–4
Lobbies/corridors	3–4
Offices	2–6
Smoking rooms	10–15
Warehousing	1–2

Notes:

* For domestic applications see pages 160 and 161.

† 18 air changes per hour is generally acceptable, plus an allowance of 0·5 l/s (1·8 m^3/h) per kW boiler rating for combustion air. Double the combustion allowance for gas boilers with a diverter flue.

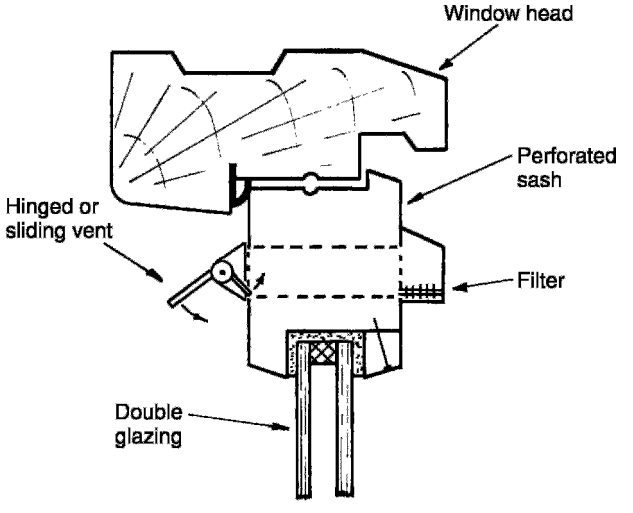
See also: BS 5925: Code of practice for ventilation principles and designing for natural ventilation.

Approved Document F (Ventilation) provides the minimum requirements for comfortable background ventilation and for preventing the occurrence of condensation. It is effected without significantly reducing the high standards of thermal insulation necessary in modern buildings.

Definitions:

- Habitable room – any room used for dwelling purposes, not solely a kitchen, utility room, bathroom or sanitary accommodation.
- Bathroom – any room with a bath and/or shower.
- Sanitary accommodation – any room with a WC.
- Ventilation opening – a means of ventilation, permanent or variable (open or closed) providing access to external air, e.g. door, window, louvre, air brick or PSV.
- PSV – passive stack ventilation is a system of vertical ducting from room ceilings to roof outlets providing ventilation by stack effect and wind passing over the roof.
- Rapid or purge ventilation – openable window or mechanical fan system.
- Background ventilation – permanent vents, usually trickle ventilators set in a window frame (see below). An air brick with a sliding 'hit and miss' ventilator could also be used.
- Whole building ventilation – continuous ventilation through background/trickle ventilators or other purpose-made vents.

Note: With rapid and background ventilation, some part of the ventilation opening should be at least 1·70 m above the floor.



Window trickle ventilator

Habitable rooms – rapid or purge ventilation should be capable of producing four air changes per hour for each room, plus a whole building ventilation rate of not less than:

Bedrooms	1	2	3	4	5
Ventilation rate (l/s)*	13	17	21	25	29

* Add 4 l/s per person where occupancy is greater than 2 persons per main bedroom and greater than 1 person in other bedrooms.
* The minimum acceptable rate for any dwelling is 0·3 l/s per m^2 total internal floor area.

Kitchen, utility room, bathroom and sanitary accommodation – local ventilation by intermittent or continuous mechanical means, i.e. an extract fan capable of achieving the following minimum rates (l/s):

Room	Intermittent**	Continuous (high)	Continuous (low)
Kitchen	30 (adjacent to hob), or 60 (elsewhere)	13	Total extract for all rooms, not less than
Utility room	30	8	the whole
Bathroom	15	8	building
Sanitary accommodation	6	6	ventilation rate.

** 15 min. overrun where fitted to an internal room. 10 mm ventilation gap under door.

Alternatively, ventilation of dwellings can be provided by any of the following:

- Background/trickle ventilators of at least 5000 mm^2 in each habitable room. Purge or rapid ventilation by fan or openable window to every habitable room. Intermittent extract fans with background ventilators for kitchen, utility room, bathroom and sanitary accommodation as table above.
- Passive stack ventilation (PSV) to kitchen, utility room, bathroom and sanitary accommodation. Positive air circulation from other rooms can be encouraged by undercutting all internal doors by 10 mm (20 mm kitchen) and omitting background ventilators in rooms with PSV extracts. Purge ventilation and background ventilators to every habitable room (see page 165).
- Continuous mechanical extract (MAVS) with background ventilators to all rooms. Purge ventilation to all habitable rooms (see page 166).
- Continuous mechanical supply and extract with heat recovery (MVHR). Purge ventilation to every habitable room (see page 167).
- Mechanical supply ventilation, also known as positive input ventilation (PIV). Background ventilators to all rooms. Purge ventilation to every habitable room (see page 169).

Note: For specific requirements relating to each of the above alternatives, see Building Regulations, Approved Document F – Ventilation, Section 1: Dwellings.

Occupiable work rooms (non-smoking) – will require a whole building ventilation air supply rate of at least 10 l/s per person. Background or trickle ventilation can be used to satisfy this objective. As a guide, 4000 mm^2 ventilation area per 10 m^2 of floor area, with an additional 400 mm^2 thereafter for every 1 m^2 of floor.

Additional rapid or purge ventilation is also required for every unit of office accommodation. This may be satisfied with an openable window area at least equivalent to a percentage of the floor area as defined in BS 5925, or a mechanical air extract directly to outside, capable of at least 10 l/s per person. For example, an office with an occupancy of 6 persons, floor area of 30 m^2 and a room height of 3 m (90 m^3 volume):

Background ventilation minimum = 10 l/s per person
Purge/rapid ventilation minimum = 10 l/s per person
Total = 20 l/s per person
$(20 \times 3600) \div 1000 = 72$ m^3/h.
$8(72 \div 90) \times 6 = 4{\cdot}8$ air changes per hour (min)

Some offices have rooms dedicated solely as smoking areas. Guidance for extract ventilation for these is on page 158.

Kitchen (for food and beverage preparation), washrooms, sanitary accommodation, photocopy and print processing rooms – local extract ventilation by continuous or intermittent means as follows:

Room function	Local extract
Printing and photocopying for more than 30 minutes in every hour	20 l/s per machine whilst in use If the room is permanently occupied, use greater value of extract and whole building ventilation rate.
Sanitary accommodation and washrooms	Intermittent air extraction of: 15 l/s per bath and shower. 6 l/s per WC and urinal.
Food and beverage preparation areas (not commercial kitchens, see page 159)	Intermittent air extraction of: 15 l/s for microwave and beverages only. 30 l/s adjacent to hob with cooker(s). 60 l/s elsewhere with cooker(s). Extract to engage automatically when food and beverage preparation equipment operates.

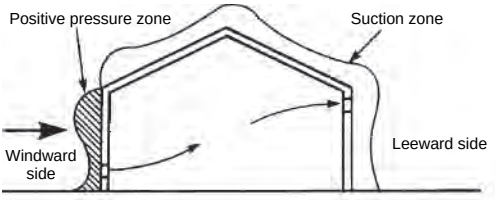
Note: Passive stack ventilation is an acceptable alternative to use of local extract by mechanical means for sanitary accommodation and washrooms, and for food and beverage preparation areas.

Further guidance and references for ventilation of non-domestic buildings, buildings other than offices and for buildings of specialised use, is provided in:

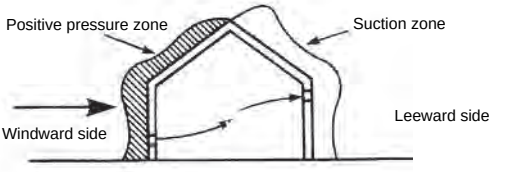
CIBSE Application Manual 10, Natural Ventilation in Non-Domestic Buildings, and Building Regulations, Approved Document F – Ventilation, Section 2, Buildings other than dwellings.

Natural ventilation is an economic means of providing air changes in a building. It uses components integral with construction such as air bricks and louvres, or openable windows. The sources for natural ventilation are wind effect/pressure and stack effect/pressure.

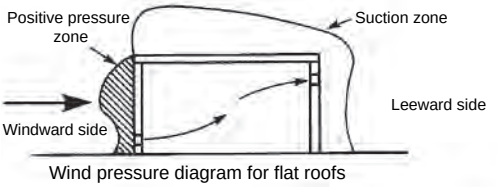
Stack effect is an application of convected air currents. Cool air is encouraged to enter a building at low level. Here it is warmed by the occupancy, lighting, machinery and/or purposely located heat emitters. A column of warm air rises within the building to discharge through vents at high level, as shown on the following page. This can be very effective in tall office-type buildings and shopping malls, but has limited effect during the summer months due to warm external temperatures. A temperature differential of at least 10 K is needed to effect movement of air, therefore a supplementary system of mechanical air movement should be considered for use during the warmer seasons.



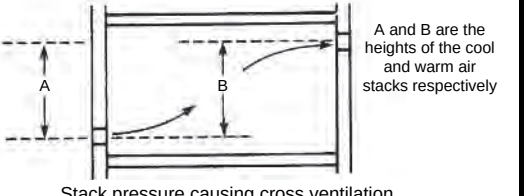
Wind pressure diagram for roofs with pitches up to 30°



Wind pressure diagram for roofs with pitches above 30°



Wind pressure diagram for flat roofs

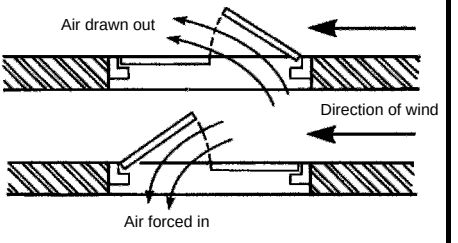


Stack pressure causing cross ventilation

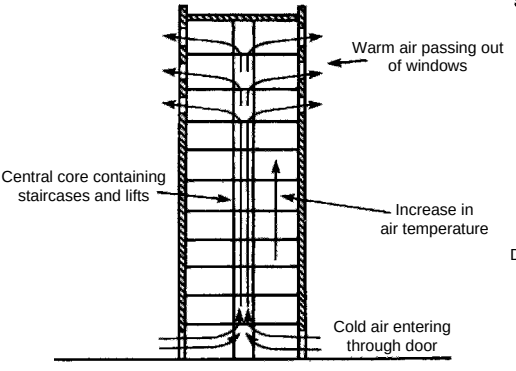
The rates of air change are determined by the building purpose and occupancy, and local interpretation of public health legislation. Public buildings usually require a ventilation rate of 30 m^3 per person per hour.

Wind passing the walls of a building creates a slight vacuum. With provision of controlled openings this can be used to draw air from a room to effect air changes. In tall buildings, during the winter months, the cool more dense outside air will tend to displace the warmer lighter inside air through windows or louvres on the upper floors. This is known as stack effect. It must be regulated otherwise it can produce draughts at low levels and excessive warmth on the upper floors.

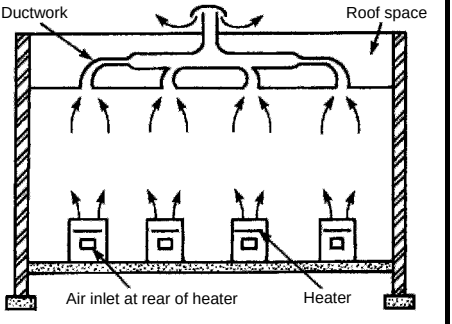
Ventilation and heating for an assembly hall or similar building may be achieved by admitting cool external air through low level convectors. The warmed air rises to high level extract ducts. The cool air intake is regulated through dampers integral with the convectors.



Wind causing ventilation through windows



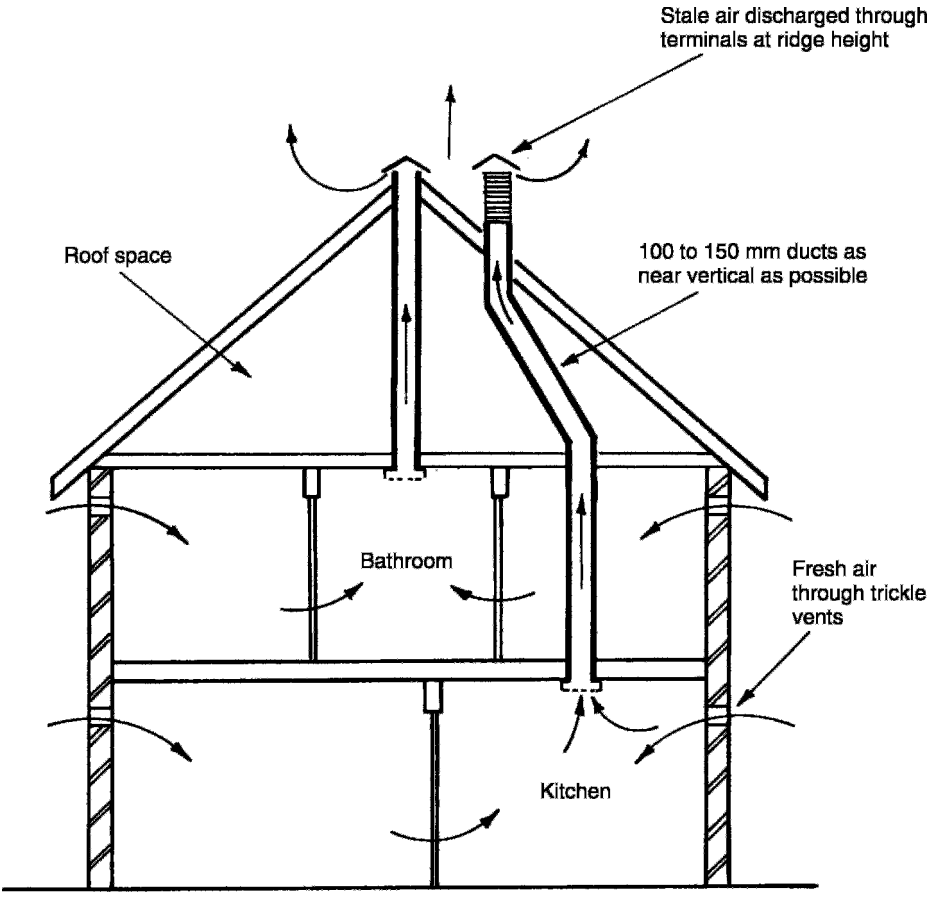
Stack pressure in a tall building



Ventilation for an assembly hall by passing fresh air through heat emitters

PSV consists of vertical or near vertical ducts of 100 to 150 mm diameter, extending from grilles set at ceiling level to terminals above the ridge of a roof. Systems can be applied to kitchens, bathrooms, utility rooms and sometimes sanitary accommodation, in buildings up to four storeys requiring up to three stacks/ducts. More complex situations are better ventilated by a Mechanical Assisted Ventilation System (MAVS), see next page.

PSV is energy efficient and environmentally friendly with no running costs. It works by combining stack effect with air movement and wind passing over the roof. It is self-regulating, responding to a temperature differential when internal and external temperatures vary.

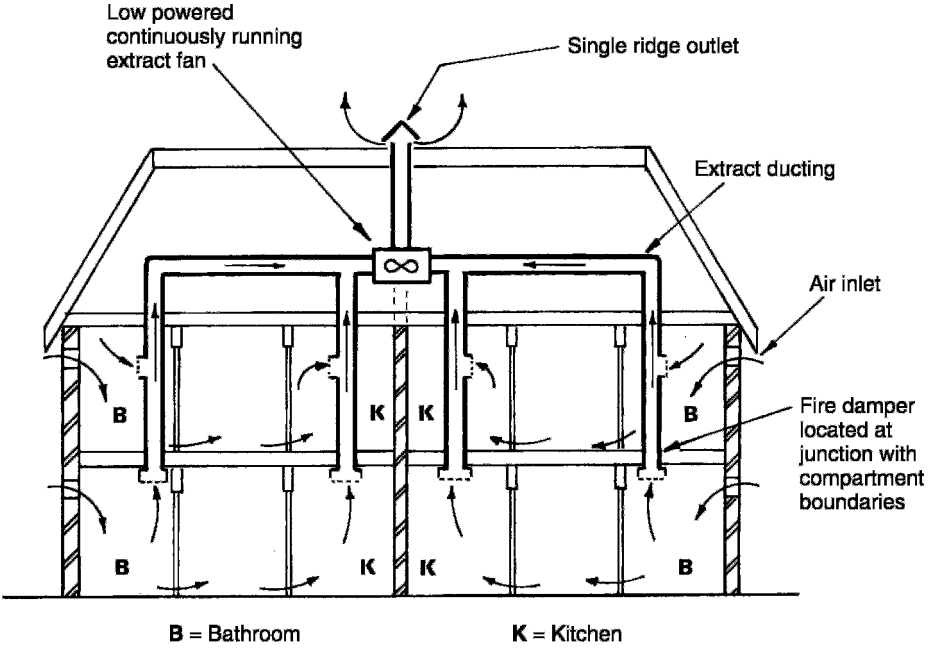


PSV to a dwelling house

Ref.: Building Regulations, Approved Document F1.

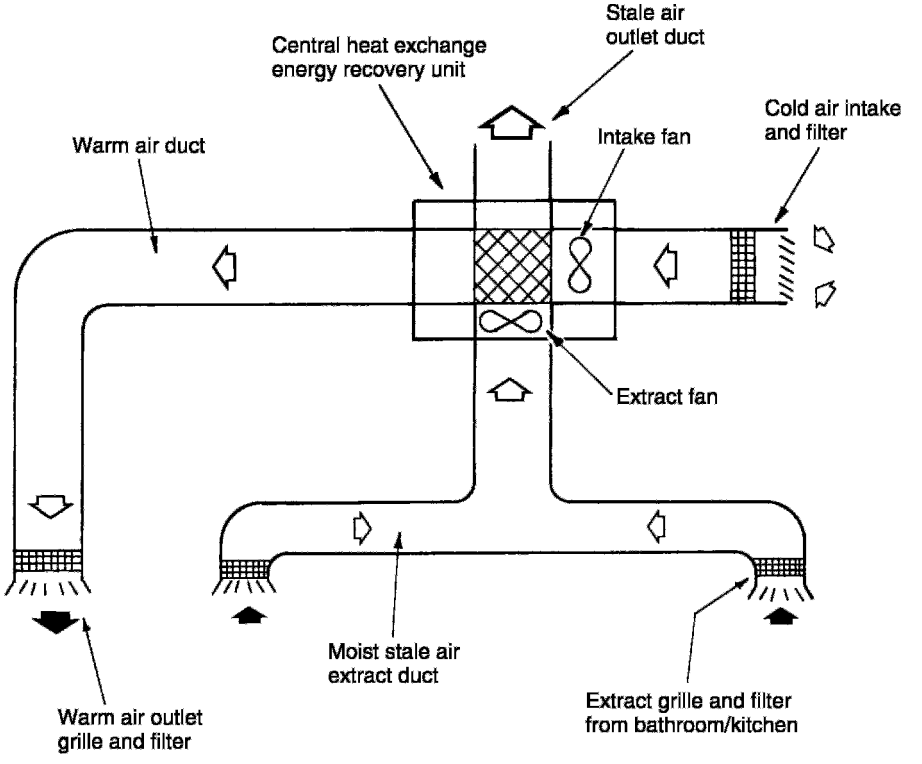
MAVS may be applied to dwellings and commercial premises where PSV is considered inadequate or impractical. This may be because the number of individual ducts would be excessive, i.e. too space consuming and obtrusive with several roof terminals. A low powered (40 W) silent running fan is normally located within the roof structure. It runs continuously and may be boosted by manual control when the level of cooking or bathing activity increases. Humidity sensors can also be used to automatically increase air flow.

MAVS are acceptable to Approved Document F1 of the Building Regulations as an alternative to the use of mechanical fans in each room. However, both PSV and MAVS are subject to the spread of fire regulations (Approved Document B). Ducting passing through a fire resistant wall, floor or ceiling must be fire protected with fire resistant materials and be fitted with a fusible link automatic damper.



MAVS in a group of flats

MVHR is a development of MAVS to include energy recovery from the warmth in fan extracted moist air from bathrooms and kitchens. The heat recovery unit contains an extract fan for the stale air, a fresh air supply fan and a heat exchanger. This provides a balanced continuous ventilation system, obviating the need for ventilation openings such as trickle ventilators. Apart from natural leakage through the building and air movement from people opening and closing external doors, the building is sealed to maximise energy efficiency. Up to 70% of the heat energy in stale air can be recovered, but this system is not an alternative to central heating. A space heating system is required and MVHR can be expected to contribute significantly to its economic use. MVHR complies with the 'alternative approaches' to ventilation of dwellings, as defined in Approved Document F1 to the Building Regulations.



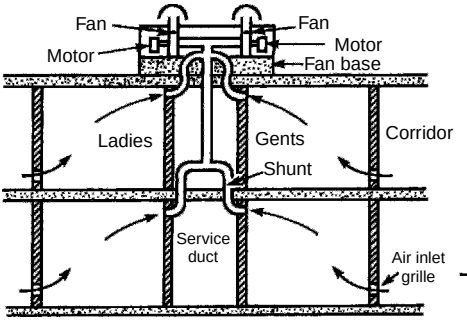
Schematic of an MVHR system of ventilation

Mechanical ventilation systems are frequently applied to commercial buildings, workshops, factories, etc., where the air change requirements are defined for health and welfare provision. There are three categories of system:

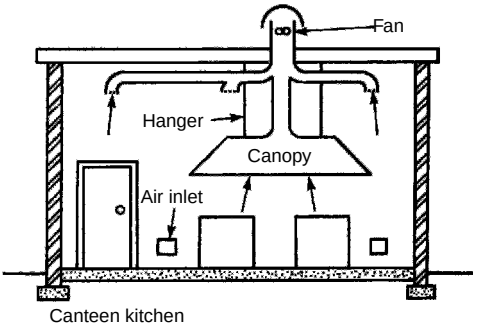
1. Natural inlet and mechanical extract
2. Mechanical inlet and natural extract
3. Mechanical inlet and mechanical extract

The capital cost of installing mechanical systems is greater than natural systems of air movement, but whether using one or more fans, system design provides for more reliable air change and air movement. Some noise will be apparent from the fan and air turbulence in ducting. This can be reduced by fitting sound attenuators and splitters as shown on page 174. Page 180 provides guidance on acceptable noise levels.

Internal sanitary accommodation must be provided with a shunt duct to prevent smoke or smells passing between rooms. In public buildings, duplicated fans with automatic changeover are also required in event of failure of the duty fan.

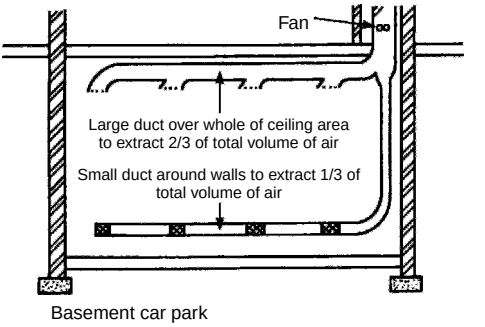


Internal sanitary accommodation



Canteen kitchen

Basement car parks require at least 6 air changes per hour and at exits and ramps where queuing occurs, local ventilation of at least 10 air changes per hour. Duplicate fans should be provided with a fan failure automatic change over.



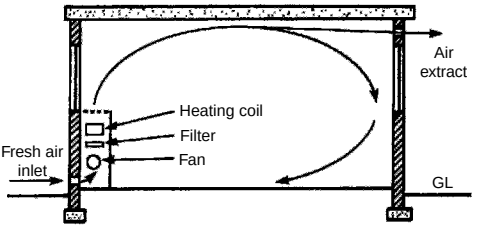
Basement car park

Fan assisted ventilation systems supplying external air to habitable rooms must have a facility to pre-heat the air. They must also have control over the amount of air extracted, otherwise there will be excessive heat loss. A mechanical inlet and mechanical extract system can be used to regulate and balance supply and emission of air by designing the duct size and fan rating specifically for the situation.

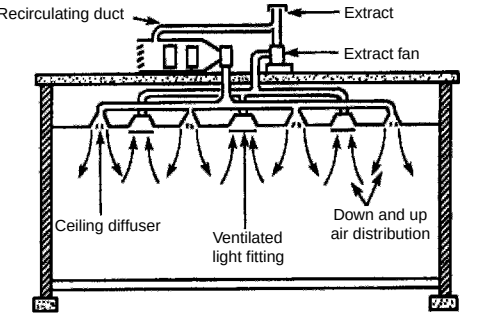
Air may be extracted through specially made light fittings. These permit the heat enhanced air to be recirculated back to the heating unit. This not only provides a simple form of energy recovery, but also improves the light output by about 10%. With any form of recirculated air ventilation system, the ratio of fresh to recirculated air should be at least 1:3. i.e. min. 25% fresh, max. 75% recirculated.

In large buildings where smoking is not permitted, such as a theatre, a downward air distribution system may be used. This provides a uniform supply of warm filtered air.

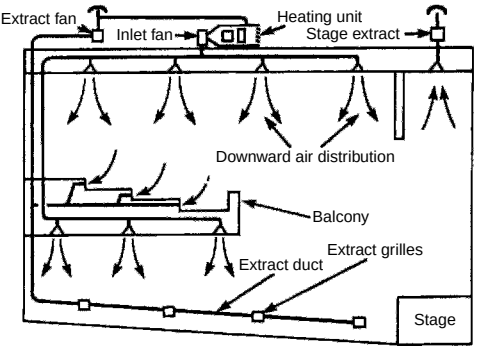
Ductwork in all systems should be insulated to prevent heat losses from processed air and to prevent surface condensation.



Mechanical inlet and natural extract



Mechanical inlet and mechanical extract for an open plan office or supermarket

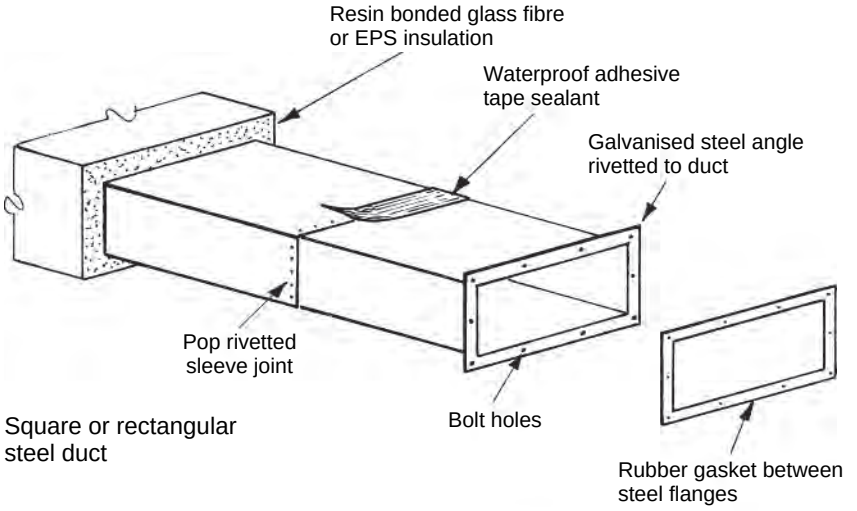


Mechanical inlet and mechanical extract for a theatre

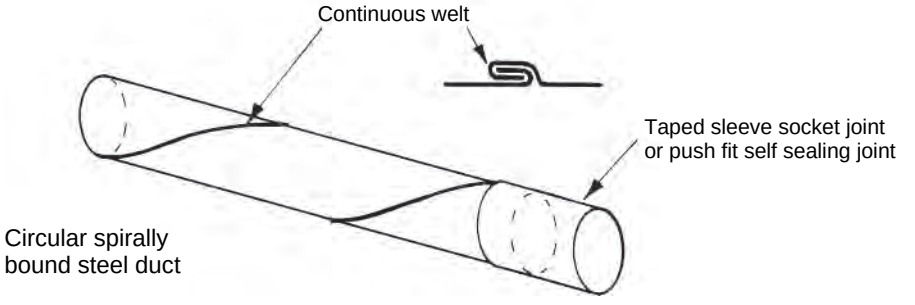
Profile – generally circular, square or rectangular but may be oval. For efficient distribution of air, the uniformity of circular ducting is preferred for the following reasons:

- less opportunity for turbulence
- less resistance to friction
- inherent rigidity
- lower heat losses or gains
- sound transfer generally less
- less potential for air leakage

Where space is restricted under floors or in suspended ceilings, rectangular ducting of high aspect ratio may be required for practical reasons (aspect ratio and conversion from circular to square or rectangular equivalent size is explained on pages 185 to 187). Square or rectangular ducting direction changes are more easily formed than with circular sections.



Square or rectangular steel duct



Circular spirally bound steel duct

Galvanised sheet steel is the most common material used for ventilation and air conditioning ducting. Factory prefabricated sections are site jointed by bolted steel angle flanges with a rubber sealing gasket, the rigid angles can also function as suspended bracket fixings. Sleeve jointing with pop-rivets and tape sealant is also used with smaller profile sections.

In addition to galvanised steel, aluminium may be used in smaller profiles or externally in non-corrosive atmospheres. Copper or stainless steel is used where the ducting forms a feature, e.g. a cooker hood. Polypropylene and uPVC piping is suitable in short lengths and small diameters, mainly for domestic applications such as extract fan extensions. Plastic materials have limitations where performance in fire is a consideration.

Material	Sheet/wall thickness (mm)	Situation	Application
Galvanised steel	0.6	Low velocity < 10 m/s	Universal
		Low pressure < 500 Pa	..
	0.8	Velocity > 10 m/s	..
		Pressure > 500 Pa	..
Aluminium or copper	0.8	Low velocity	Features
Stainless steel	As galvanised steel		Features
UPVC	3.0	Low velocity	Domestic
Polypropylene	3.0	Low velocity	Domestic
Resin bonded glass fibre	3.0	Low velocity	Warm air heating

Apart from standard plastic pipe profiles (100 and 150 mm nominal diameter drainage pipes), most ducting is factory produced to the designer's specification. It is unrealistic for sheet metal fabricators to produce standard sections due to unknown demand and the space requirement for storage.

Flexible ducts are useful for short connections from air distribution boxes or plenums to several diffusers within close proximity. They are also useful for correcting misalignments and for convenient connections to fan housings and terminals. Flexible connections to fans will help to reduce vibration and sound. Flexible ducting is produced in corrugations made up in a concertina format from thin sheet aluminium or from spirally wound steel reinforced fabric. Lengths should be limited to as short as possible, as the concertina effect will impede air flow and create noise. Also, flexible ducting is more likely to suffer damage and leakage. Jointing is by taped sleeve and jubilee clip.

Types of Fan

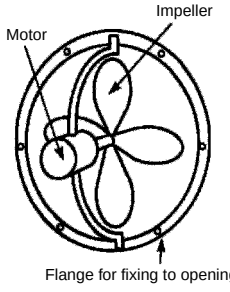
Propeller fan – does not create much air pressure and has limited effect in ductwork. Ideal for use at air openings in windows and walls.

Axial flow fan – can develop high pressure and is used for moving air through long sections of ductwork. The fan is integral with the run of ducting and does not require a base.

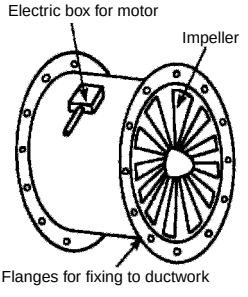
Bifurcated axial flow fan – used for moving hot gases, e.g. flue gases, and greasy air from commercial cooker hoods.

Cross-flow or tangential fan – used in fan convector units.

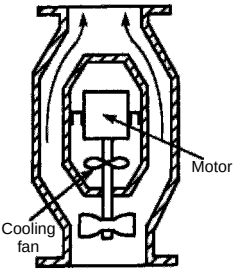
Centrifugal fan – can produce high pressure and has the capacity for large volumes of air. Most suited to larger installations such as air conditioning systems. It may have one or two inlets. Various forms of impeller can be selected depending on the air condition. Variable impellers and pulley ratios from the detached drive motor make this the most versatile of fans.



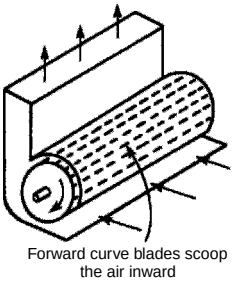
Propeller fan



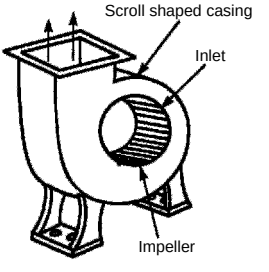
Axial flow fan



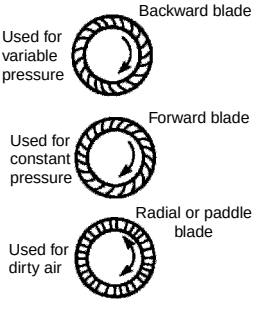
Bifurcated axial flow fan



Cross-flow fan



Centrifugal fan



Types of impeller used with centrifugal fans

Fan performance depends very much on characteristics such as type and configuration of components. Given a standard set of criteria against which a fan's performance is measured, i.e. 20°C dry bulb temperature, 101·325 kPa (1013 mb) atmospheric pressure, 50% relative humidity and 1.2 kg/m^3 air density, any variation in performance can be predicted according to the following fan laws:

- Discharge (volumetric air flow) varies directly with the fan speed.

$$Q2 = Q1(N2/N1)$$

- Fan pressure is proportional to the fan speed squared.

$$P2 = P1(N2/N1)^2$$

- Fan power is proportional to the fan speed cubed.

$$W2 = W1(N2/N1)^3$$

where: Q = air volume in m^3/s
N = fan speed in rpm
P = pressure in pascals (Pa)
W = power in watts or kilowatts.

E.g. a mechanical ventilation system has the following fan characteristics:

Discharge (Q1) = 6 m^3/s
Pressure (P1) = 400 Pa
Power (W1) = 3 kW
Speed (N1) = 1500 rpm

If the fan speed is reduced to 1000 rpm, the revised performance data will apply:

Discharge (Q2) = $6(1000/1500) = 4$ m^3/s
Pressure (P2) = $400(1000/1500)^2 = 178$ Pa
Power (W2) = $3000(1000/1500)^3 = 890$ W

$$\text{Fan efficiency} = \frac{\text{Total fan pressure} \times \text{Air volume}}{\text{Power}} \times \frac{100}{1}$$

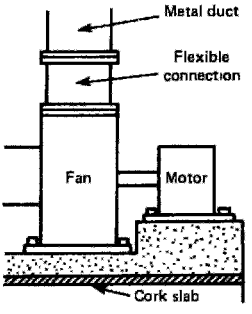
So, for this example: $\frac{178 \times 4}{890} \times \frac{100}{1} = 80\%$

Fans and air turbulence can be a significant noise source in air distribution systems. System accessories and fittings such as ductwork material, grilles/diffusers, mixing boxes, tee junctions and bends can compound the effect of dynamic air. Ducts of large surface area may need to be stiffened to prevent reverberation.

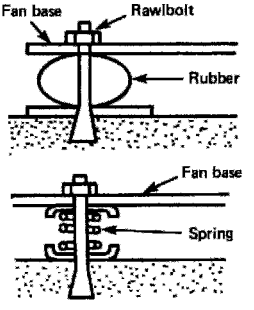
Fans may be mounted on a concrete base, with either cork, rubber or fibre pad inserts. Strong springs are an alternative. Duct connections to a fan should have a flexible adaptor of reinforced PVC.

Sound attenuation in ducting can be achieved by continuously lining the duct with a fire resistant, sound absorbing material. Where this is impractical, strategically located attenuators/silencers composed of perforated metal inserts or a honeycomb of sound absorbent material can be very effective. These have a dual function as system sound absorbers and as absorbers of airborne sound transmission from adjacent rooms sharing the ventilation system.

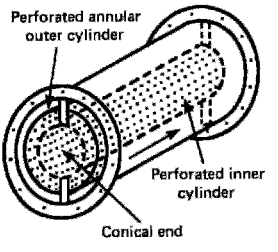
To prevent air impacting at bends, a streamlining effect can be achieved by fixing vanes or splitters to give the air direction.



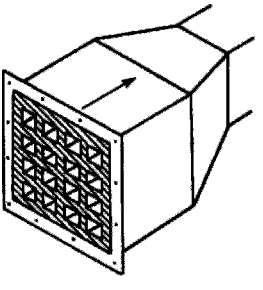
Use of cork slab and flexible connection



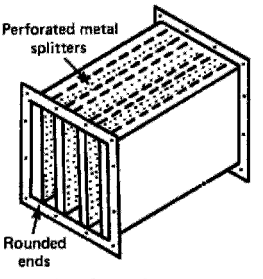
Use of rubber or spring mountings



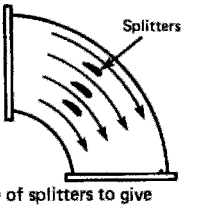
Use of perforated metal cylinder



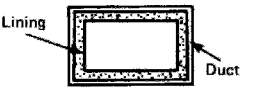
Use of acoustically absorbent honeycomb



Use of perforated metal splitters



Use of splitters to give streamline flow



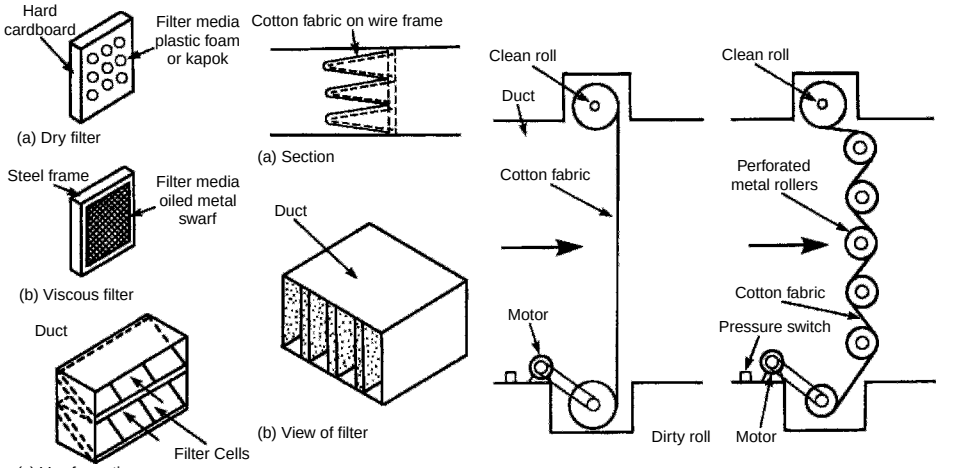
Use of acoustically absorbent lining of mineral wool

Cell or panel – flat or in a vee formation to increase the surface contact area. Available in dry or wet (viscous) composition in disposable format for simple fitting within the ductwork. A rigid outer frame is necessary to prevent flanking leakage of dirty air. Dry filters can be vacuum cleaned to extend their life, but in time will be replaced. The viscous filter is coated with an odourless, non-toxic, non-flammable oil. These can be cleaned in hot soapy water and recoated with oil.

Absolute – a type of dry cell filter produced from dense glass paper. The paper is folded into deep pleats to create a series of vee formations arranged parallel to the air flow to increase surface contact. Some manufacturers apply cardboard or thin aluminium interleaves to support the glass paper and to channel the air through the filter depth.

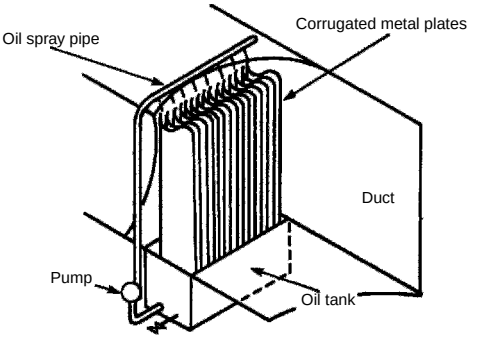
Bag – a form of filtration material providing a large air contact area. When the fan is inactive the bag will hang limply unless wire reinforced. It will resume a horizontal profile during normal system operation. Fabric bags can be washed periodically and replaced.

Roller – operated manually or by pressure sensitive switch. As the filter becomes less efficient, resistance to air flow increases. The pressure effects a detector which engages a motor to bring down clean fabric from the top spool. Several perforated rollers can be used to vee format and increase the fabric contact area.

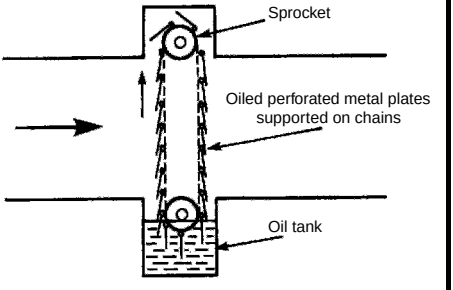


Viscous – these have a high dust retention capacity and are often specified for application to industrial situations. An improvement on the panel type has close spaced corrugated metal plates continuously sprayed with oil. A rotating variation has filter plates hung from chains. The lower plates in the cycle pass through a bath of oil which removes attached particles and resurfaces the plates with clean oil.

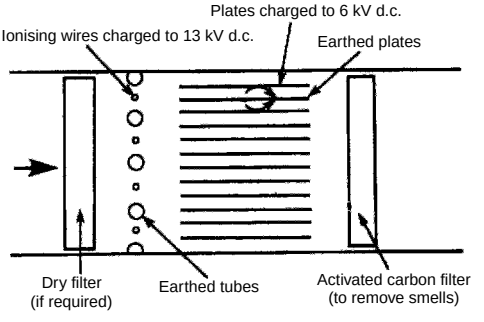
Electrostatic unit – this has an ionising area which gives suspended dust particles a positive electrostatic charge. These are conveyed in the air stream through metal plates which are alternately charged positive and earthed negative. Positively charged particles are repelled by the positive plates and attracted to the negative plates. The negative plates can also be coated with a thin layer of oil or gel for greater retention of dust. The unit can have supplementary, preliminary and final filters as shown below, giving an overall efficiency of about 99%.



Automatic viscous filter (oil-spray type)



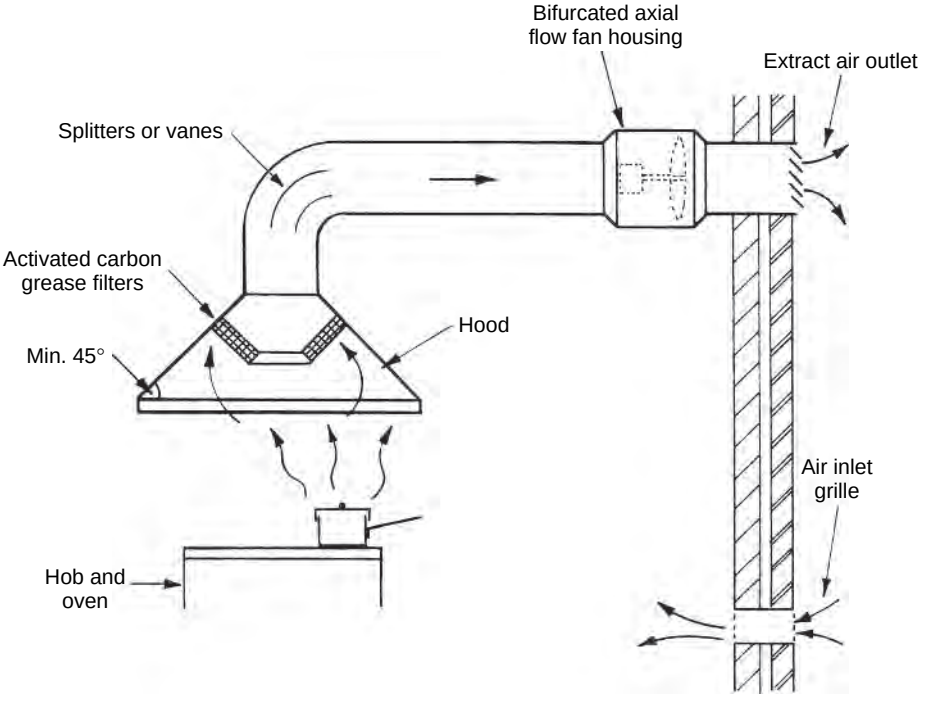
Automatic viscous filter (rotating type)



Electrostatic filter

Activated carbon – otherwise known as activated charcoal. A disposable filter composed of carbon particles resembling pieces of coconut shell and arranged to provide a large surface contact area. A glass fibre matting is often used to contain the carbon shells. This type of filter is used specifically in commercial cooker hoods and in other greasy, odorous atmospheres, as the carbon is extremely absorbent. The attraction between hot greasy fumes and carbon is termed adsorption. Activated carbon filters are disposable and must be easily accessible for inspection and replacement.

Typical application –



Simple ducted air systems, typical of those serving internal WCs and bathrooms, operate at relatively low air velocity with little frictional resistance or pressure drop. In these situations the relationship between air flow and duct diameter can be expressed as:

$$Q = 6{\cdot}3 \times 10^{-7} \times \sqrt{d^5 \times h \div L}$$

where: Q = air flow rate in m^3/sec.
d = duct diameter in mm.
h = pressure drop in mm water gauge.
L = length of duct in metres.

To determine duct diameter from design input data, the formula is represented:

$$d = 305 \times \sqrt[5]{Q^2 \times L \div h}$$

E.g. A 10 m long ventilation duct is required to provide air at 0·10 m^3/sec at a pressure drop of 0·15 mm wg.

0·15 mm = 1·5 pascals (Pa) (over 10 m of ducting)
= 0·015 mm per m, or 0·15 Pa per m.

$d = 305 \times \sqrt[5]{(0{\cdot}10)^2 \times 10 \div 0{\cdot}15}$

$d = 305 \times \sqrt[5]{0{\cdot}6667}$

$d = 305 \times 0{\cdot}922 = 281$ mm diameter.

To check that the calculated diameter of 281 mm correlates with the given flow rate (Q) of 0·10 m^3/sec:

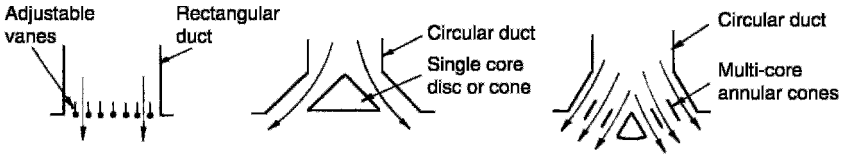
$Q = 6{\cdot}3 \times 10^{-7} \times \sqrt{d^5 \times h \div L}$

$Q = 6{\cdot}3 \times 10^{-7} \times \sqrt{(281)^5 \times 0{\cdot}15 \div 10}$

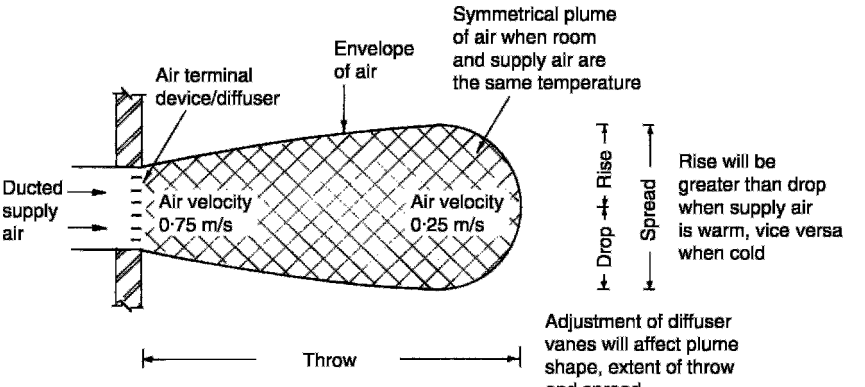
$Q = 6{\cdot}3 \times 10^{-7} \times 162110$

$Q = 0{\cdot}102$ m^3/sec

Diffusers – these vary considerably in design from standard manufactured slatted grilles to purpose-made hi-tech profiled shapes and forms compatible with modern interiors. The principal objective of air distribution and throw must not be lost in these designs.

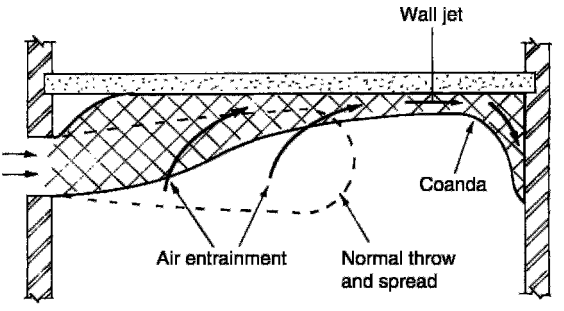


Some types of diffuser (section)



Unimpeded air distribution

Coanda effect – diffuser location must be selected to avoid unwanted draughts, air delivery impacting on beams, columns and other air deliveries. Where structural elements are adjacent, such as a wall and ceiling, the air delivery may become entrained and drawn to the adjacent surface. This can be advantageous as the plume of air throw, although distorted, may extend to run down the far wall as well.



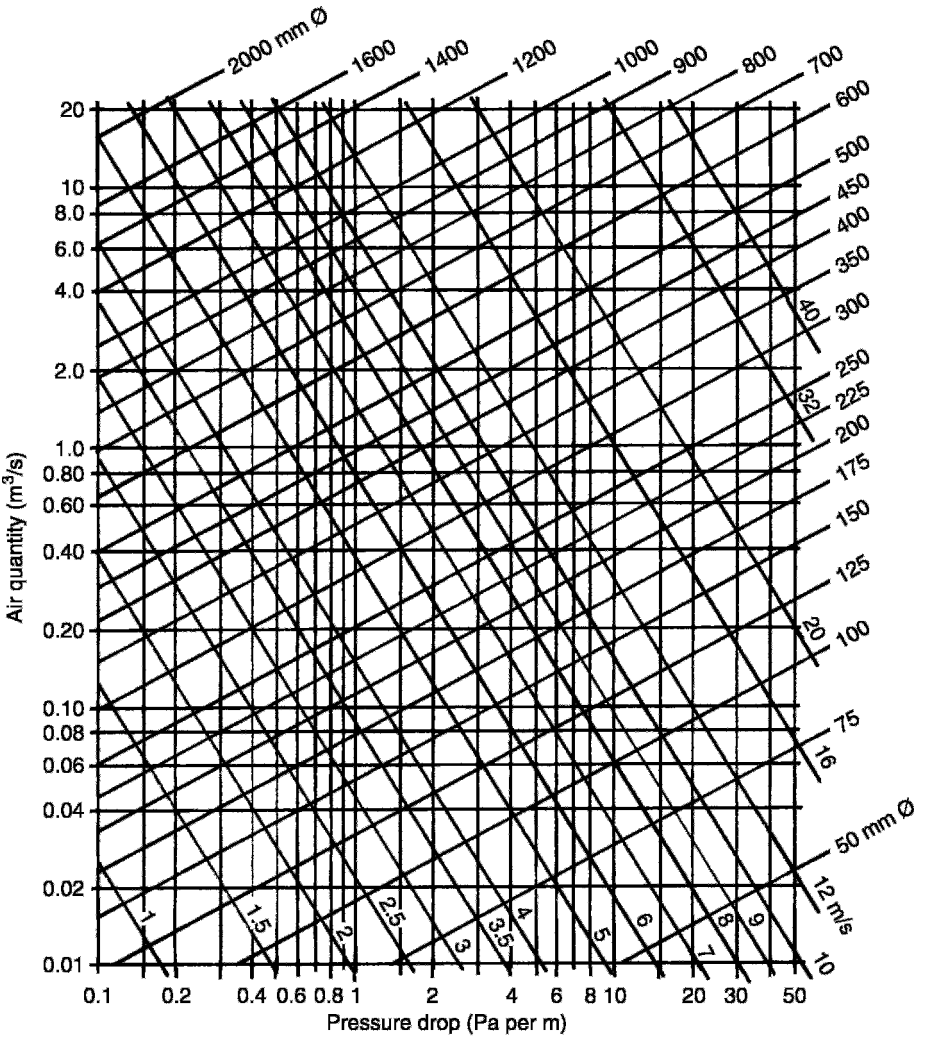
Coanda effect and wall jet

Air velocity within a room or workplace should be between 0·15 and 0·50 m/s, depending on the amount of activity. Sedentary tasks such as desk work will fall into the range of 0·15 to 0·30 m/s, whilst more active assembly work, shopwork and manufacturing, between 0·30 and 0·50 m/s. These figures are designed to provide a feeling of freshness, to relieve stagnation without noise distraction from air movement equipment.

Conveyance of air and discharge through ducting and outlet diffusers will produce some noise. This should not be distracting and must be maintained at an unobtrusive level. As the extent of occupancy activity and/or machinery and equipment noise increases, so may the ducted air velocity, as background noise will render sound from air movement unnoticeable. For design purposes, the greater the ducted air velocity, the smaller the duct size and the less space consuming the ducting. However, some regard must be made for acceptable ducted air noise levels and the following table provides some guidance:

Situation	Ducted air velocity (m/s)
Very quiet, e.g. sound studio, library, study, operating theatres	1·5–2·5
Fairly quiet, e.g. private office, habitable room, hospital ward	2·5–4·0
Less quiet, e.g. shops, restaurant, classroom, general office	4·0–5·5
Non-critical, e.g. gyms, warehouse, factory, department store	5·5–7·5

Estimation of duct size and fan rating can be achieved by simple calculations and application to design charts. The example below is a graphical representation of the quantity of air (m^3/s), friction or pressure reduction (N/m^2 per m) or (Pa per m) and air velocity (m/s) in circular ductwork. Conversion to equivalent size square or rectangular ductwork is shown on pages 185, 186 and 187.



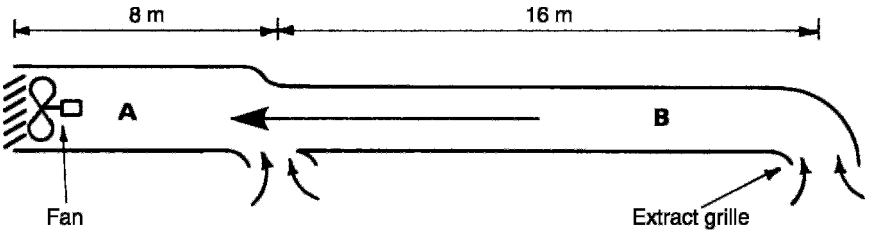
General air flow data for circular ducts

For mechanical supply and extract systems, the air volume flow rate or quantity of air can be calculated from the following formula:

$$Q(m^3/s) = \frac{\text{Room volume} \times \text{Air changes per hour}}{\text{Time in seconds}}$$

Air changes per hour can be obtained from appropriate legislative standards for the situation or the guidance given on pages 158 and 159.

E.g.



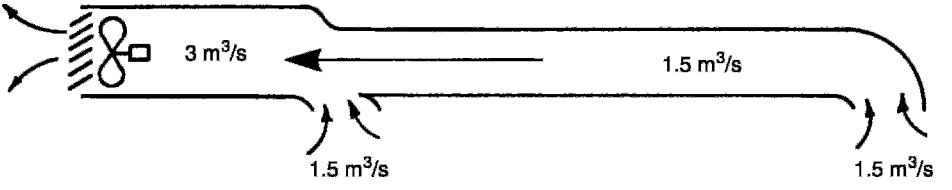
Room volume = 1800 m^3, requiring six air changes per hour

The ducted extract air system shown is a simple straight run, with duct A effectively 8 m long and duct B effectively 16 m long. Where additional bends, tees, offsets and other resistances to air flow occur, a nominal percentage increase should be added to the actual duct length. Some design manuals include 'k' factors for these deviations and an example is shown on pages 188 and 189.

For the example given:

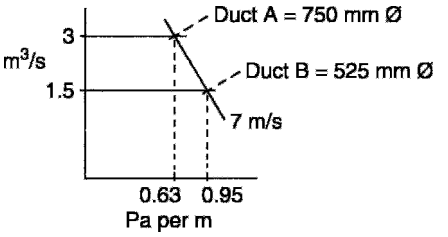
$$Q = \frac{1800 \times 6}{3600} = 3\ m^3/s$$

Disposition of extract grilles and room function will determine the quantity of air removed through each grille and associated duct. In this example the grilles are taken to be equally disposed, therefore each extracts 1·5 m^3/s. Duct A therefore must have capacity for 3 m^3/s and duct B, 1·5 m^3/s.

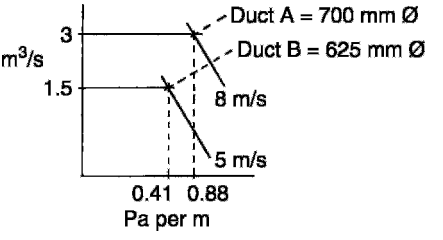


There are several methods which may be used to establish ventilation duct sizes, each having its own priority. The following shows three of the more popular, as applied to the design chart on page 181.

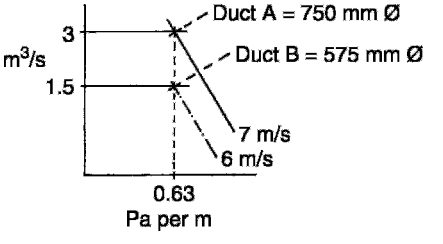
- Equal velocity – applied mainly to simple systems where the same air velocity is used throughout. For example, selected velocity is 7 m/s (see page 180), therefore the design chart indicates:



- Velocity reduction – air velocity is selected for the main section of ductwork and reduced for each branch. For example, selected air velocities for ducts A and B are 8 m/s and 5 m/s respectively:



- Equal friction/constant pressure drop – air velocity is selected for the main section of ductwork. From this, the friction is determined and the same figure applied to all other sections. For example, selected air velocity through duct A is 7 m/s:



Using the example on page 182 with the equal velocity method of duct sizing shown on page 183, the fan will be required to extract 3 m^3 of air per second at a pressure of:

Duct (A) = 8 m × 0·63 Pa per m = 5·04 Pa
Duct (B) = 16 m × 0·95 Pa per m = 15·20 Pa

20·24 Pa (i.e. 20·25)

System pressure loss is calculated from: $k = P/Q^2$

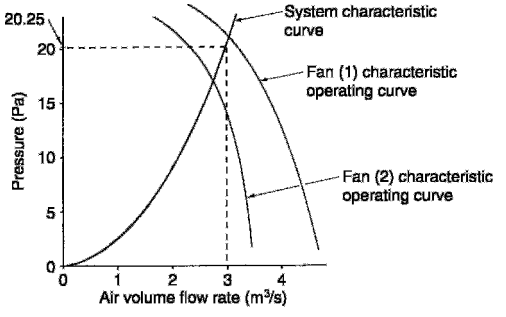
where: k = pressure loss coefficient
P = pressure loss (Pa)
Q = air volume flow rate (m^3/s)

Therefore: $k = 20{\cdot}25/3^2 = 2{\cdot}25$

Using this coefficient, the system characteristic curve may be drawn between the operating air volume flow rate of 3 m^3/s down to a nominal low operating figure of, say, 0.5 m^3/s. By substituting figures in this range in the above transposed formula, $P = k \times Q^2$ we have:

$P = 2{\cdot}25 \times (0{\cdot}5)^2 = 0{\cdot}56$ Pa	[0·5 m^3/s @ 0·56 Pa]
$P = 2{\cdot}25 \times (1{\cdot}0)^2 = 2{\cdot}25$ Pa	[1·0 m^3/s @ 2·25 Pa]
$P = 2{\cdot}25 \times (1{\cdot}5)^2 = 5{\cdot}06$ Pa	[1·5 m^3/s @ 5·06 Pa]
$P = 2{\cdot}25 \times (2{\cdot}0)^2 = 9{\cdot}00$ Pa	[2·0 m^3/s @ 9·00 Pa]
$P = 2{\cdot}25 \times (2{\cdot}5)^2 = 14{\cdot}06$ Pa	[2·5 m^3/s @ 14·06 Pa]
$P = 2{\cdot}25 \times (3{\cdot}0)^2 = 20{\cdot}25$ Pa	[3·0 m^3/s @ 20·25 Pa]

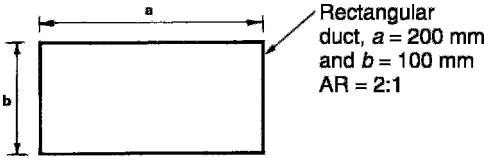
Plotting these figures graphically against fan manufacturers data will provide an indication of the most suitable fan for the situation:



Select fan (1), as with variable settings this would adequately cover the system design characteristics.

Some ventilation design manuals limit data presentation to circular profile ductwork only. It is often more convenient for manufacturers and installers if square or rectangular ductwork can be used. This is particularly apparent where a high aspect ratio profile will allow ducting to be accommodated in depth restricted spaces such as suspended ceilings and raised floors.

Aspect ratio:



The numerical relationship between dimension a to b. Square = 1:1.

Conversion of circular ductwork to square or rectangular (or vice versa) using the equal velocity of flow formula:

$$d = \frac{2ab}{a + b}$$

where: d = duct diameter
a = longest dimension of rectangular duct
b = shortest dimension of rectangular duct.

E.g. a 400 mm diameter duct to be converted to a rectangular profile of aspect ratio 3:1.

$$a = 3b$$

Substituting in the above formula:

$$400 = \frac{2 \times 3b \times b}{3b + b} = \frac{6b^2}{4b} = \frac{6b}{4}$$

Therefore:

$$b = \frac{4 \times 400}{6} = 267 \text{ mm}$$

$$a = 3b = 800 \text{ mm}$$

For equal volume of flow and pressure drop there are two possible formulae:

1. $$d = 1{\cdot}265 \times \left[\frac{(a \times b)^3}{a + b}\right]^{0{\cdot}2}$$

2. $$d = \left[\frac{32(a \times b)^3}{\pi^2(a + b)}\right]^{0{\cdot}2}$$

Notes: 0·2 represents the 5th root of data in brackets.
Formulae assume identical coefficient of friction occurs between circular and rectangular ducts, i.e. same material used.

E.g. circular duct of 400 mm diameter to be converted to rectangular having an aspect ratio of 3:1. Therefore, a = 3b.

Substituting in formula 1:

$$400 = 1{\cdot}265 \times \left[\frac{(3b \times b)^3}{3b + b}\right]^{0{\cdot}2}$$

$$400 = 1{\cdot}265 \times \left[\frac{(3b^2)^3}{4b}\right]^{0{\cdot}2}$$

From this, b = 216 mm

a = 3b = 648 mm

Substituting in formula 2:

$$400 = \left[\frac{32(3 \times b^2)^3}{\pi^2(3b + b)}\right]^{0{\cdot}2}$$

$$400 = \left[\frac{3{\cdot}242(27b^5)}{4}\right]^{0{\cdot}2}$$

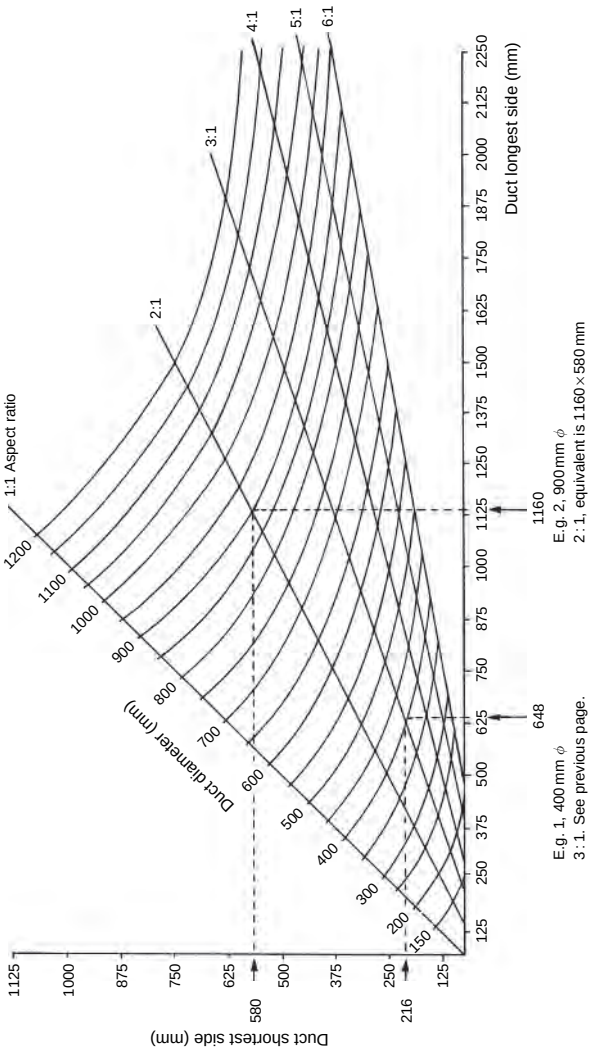
From this, b = 216 mm

a = 3b = 648 mm

See next page for a simplified graphical conversion.

Note: A circular duct has diameter equivalent to the side of a square duct multiplied by 1.1.

Most ducting is sized using the same pressure drop or pressure loss per metre length. Larger ducting in a ventilation system will require a higher velocity to maintain a pressure drop equivalent to the smaller distribution ducting that it serves. The higher velocity will generate some increase in air movement noise, but this is not usually a problem as larger ducting is generally remote from occupied areas.



Approximate comparative ducting profiles

There are many scientific applications to frictional or pressure losses created as air flows through ductwork. One of the most established is derived from Bernoulli's theorem of energy loss and gain as applied to fluid and air flow physics. Interpretation by formula:

$$h = k\left(\frac{V^2}{2g} \times \frac{\text{Density of air}}{\text{Density of water}}\right)$$

Where: h = head or pressure loss (m)
k = velocity head loss factor
V = velocity of air flow (m/s)
g = gravity factor (9·81)
density of air = 1·2 kg/m^3 @ 20°C and 1013 mb
density of water = 1000 kg/m^3

'k' factors have been calculated by experimentation using different ductwork materials. They will also vary depending on the nature of fittings, i.e. tees, bends, etc., the profile, extent of direction change, effect of dampers and other restrictions to air flow. Lists of these factors are extensive and can be found in ventilation design manuals. The following is provided as a generalisation of some mid-range values for illustration purposes only:

Duct fitting	Typical 'k' factor
Radiused bend (90°)	0·30
Mitred bend (90°)	1·25
Branch (tee) piece (90°)	0·40–1·70*
Branch (tee) piece (45°)	0·12–0·80*
Reductions (abrupt)	0·25
Reductions (gradual)	0·04
Enlargements (abrupt)	0·35
Enlargements (gradual)	0·20
Obstructions (louvres/diffusers)	1·50
Obstructions (wire mesh)	0·40
Obstructions (dampers)	0·20–0·50†

Notes:

* Varies with area ratios of main duct to branch duct.

† Varies depending on extent of opening.

E.g. Calculate the pressure loss in a 10 m length of 400 mm diameter ductwork containing four 90° radiused bends. Velocity of air flow is 5 m/s.

$$k = \text{four No. bends @ } 0{\cdot}30 = 1{\cdot}20$$

Bernoulli's formula:

$$h = 1{\cdot}2\left(\frac{5^2}{2 \times 9{\cdot}81} \times \frac{1{\cdot}2}{1000}\right)$$

$$h = 0{\cdot}00183 \text{ m or } 1{\cdot}83 \text{ mm or approx. } 18 \text{ Pa.}$$

From the duct sizing chart on page 181, the pressure loss for a 400 mm diameter duct at 5 m/s is approximately 0·8 Pa per metre.

For 10 m of ductwork = $10 \times 0{\cdot}8 = 8$ Pa.

Total pressure loss = 18 Pa + 8 Pa = 26 Pa.

An alternative to the duct sizing chart for finding air flow resistance is application of another established fluid and air flow theorem attributed to D'Arcy. This can be used for pipe sizing as well as for sizing small ducts.

D'Arcy's formula:

$$h = \frac{4fLV^2}{2gD} \times \frac{\text{Density of air}}{\text{Density of water}}$$

where: f = friction coefficient, 0·005–0·007 depending on duct material

L = length of duct (m)

D = duct diameter (m).

Using the above example of a 10 m length of 400 mm (0·4 m) ductwork conveying air at 5 m/s:

$$h = \frac{4 \times 0{\cdot}0052 \times 10 \times 5^2}{2 \times 9{\cdot}81 \times 0{\cdot}4} \times \frac{1{\cdot}2}{1000}$$

h = 0·0008 m or 0·8 mm or approx. 8 Pa.

Ventilation System Heating Load

When designing ventilation systems, provision must be made for the displacement of heat energy resulting from the movement of air. This is necessary for maintenance of the building or room ambient temperature. Also, to prevent cold draughts and condensation.

Cold supply air is pre-heated to discharge at the same temperature as the design air temperature for the room served. This will have no real effect on any separate heating system and can be regulated independently by a control thermostat. The following formula can be used to establish the ducted air heater rating in kW, relative to design temperature parameters:

Heater rating = m × Shc × Temp. diff. (int. – ext.)

Where:

m = mass air flow rate (kg/s)

Shc = Specific heat capacity of air (1·0 kJ/kg K)

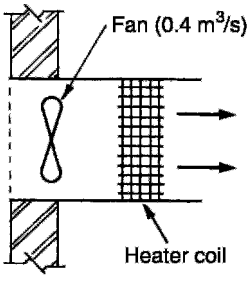
Temp. diff. = Temperature differential between internal room air and external supply air (K)

Air flow rate by volume (Q) is calculated in m^3/s. To convert this to mass air flow rate in kg/s, the volume rate is multiplied by air density (ρ) of 1·2 kg/m^3.

Therefore:

Heater rating = Q × ρ × Shc × Temp. diff. (int. – ext.)

For example, a room with total fabric and infiltration heat losses of 3 kW (see method of calculation on page 125), with air supply and temperature design factors as given below:



Heater rating = 0·4 × 1·2 × 1·0 × (22 – –4)
= 12·48 kW

Air duct heater calculation

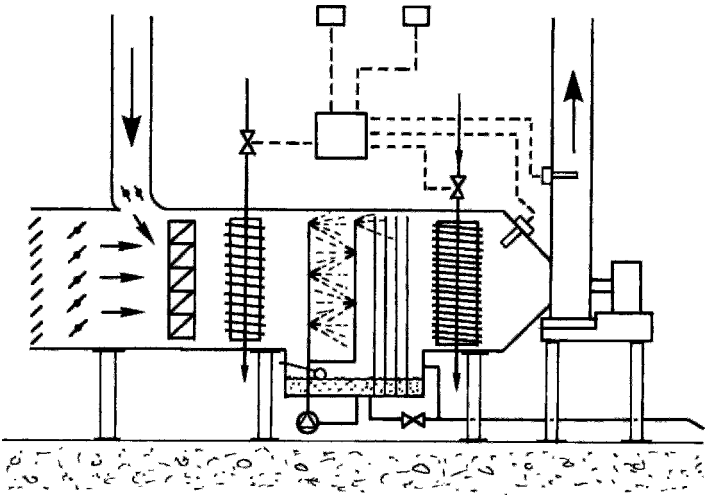
Therefore if the ducted air is required to supply all heating needs, then 12·48 kW is added to the room losses of 3 kW, bringing the total heat input to 15·48 kW. If the ducted air system is to provide for the design room heat loss of 3 kW, the discharge air temperature (T) can be found by rewriting the formula:

Room heat losses = Q × ρ × Shc × (T – int. air temp.)

Or: T = [Room heat losses ÷ (Q × ρ × Shc)] + 22

T = [3 ÷ (0·4 × 1·2 × 1·0)] + 22 = 28·25°C

6 AIR CONDITIONING



AIR CONDITIONING – PRINCIPLES
CENTRAL PLANT SYSTEM
AIR PROCESSING UNIT
HUMIDIFIERS
VARIABLE AIR VOLUME
INDUCTION (AIR/WATER) SYSTEM
FAN-COIL (AIR/WATER) UNIT AND INDUCTION DIFFUSER
DUAL DUCT SYSTEM
CHILLED BEAMS AND CEILINGS
COOLING SYSTEMS
REFRIGERATION AND SYSTEM CHARACTERISTICS
PACKAGED AIR CONDITIONING SYSTEMS
PSYCHROMETRICS – PROCESSES AND APPLICATIONS
HEAT PUMPS
HEAT RECOVERY DEVICES
HEALTH CONSIDERATIONS
BUILDING RELATED ILLNESSES

Air conditioning is achieved by developing the principles of moving air in ducted ventilation systems to include a number of physical and scientific processes which enhance the air quality. The objective is to provide and maintain internal air conditions at a pre-determined state, regardless of the time of year, the season and the external atmospheric environment. For buildings with human occupancy, the design specification is likely to include an internal air temperature of 19–23°C and relative humidity between 40 and 60%.

The following is a glossary of some of the terminology used in air conditioning design:

Dew point – temperature at which the air is saturated (100% RH) and further cooling manifests in condensation from water in the air.

Dry bulb temperature – temperature shown by a dry sensing element such as mercury in a glass tube thermometer (°C db).

Enthalpy – total heat energy, i.e. sensible heat + latent heat. Specific enthalpy (kJ/kg dry air).

Entropy – measure of total heat energy in a refrigerant for every degree of temperature (kJ/kg°C).

Latent heat – heat energy added or removed as a substance changes state, whilst temperature remains constant, e.g. water changing to steam at 100°C and atmospheric pressure (W).

Moisture content – amount of moisture present in a unit mass of air (kg/kg dry air).

Percentage saturation – ratio of the amount of moisture in the air compared with the moisture content of saturated air at the same dry bulb temperature. Almost the same as RH and often used in place of it.

Relative humidity (RH) – ratio of water contained in air at a given dry bulb temperature, as a percentage of the maximum amount of water that could be held in air at that temperature.

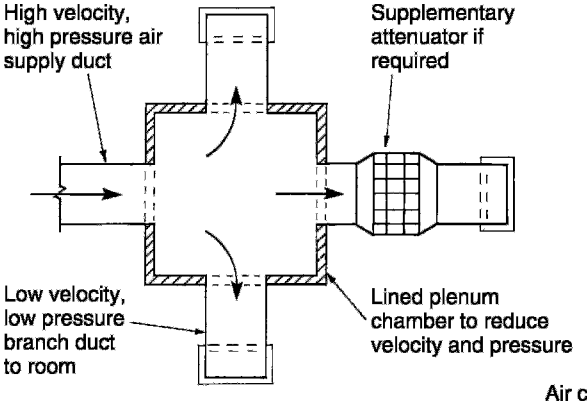
Saturated air – air at 100% RH.

Sensible heat – heat energy which causes the temperature of a substance to change without changing its state (W).

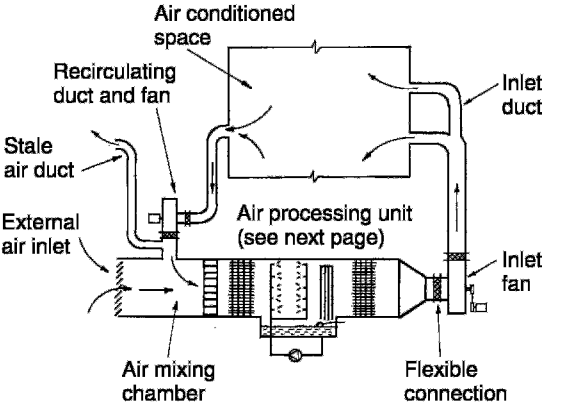
Specific volume – quantity of air per unit mass (m^3/kg).

Wet bulb temperature – depressed temperature measured on mercury in a glass thermometer with the sensing bulb kept wet by saturated muslin (°C wb).

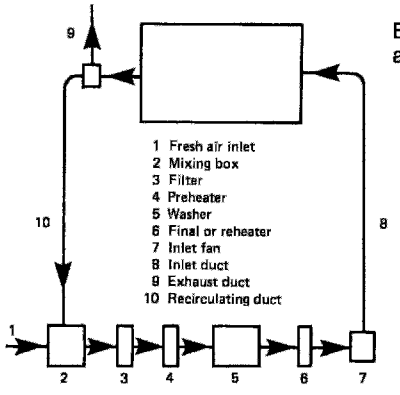
This system is used where the air condition can be the same throughout the various parts of a building. It is also known as an all air system and may be categorised as low velocity for use in buildings with large open spaces, e.g. supermarkets, theatres, factories, assembly halls, etc. A variation could incorporate a heating and cooling element in sub-branch ductwork to smaller rooms such as offices. Very large and high rise buildings will require a high velocity and high pressure to overcome the resistances to air flow in long lengths of ductwork. Noise from the air velocity and pressure can be reduced just before the point of discharge, by incorporating an acoustic plenum chamber with low velocity sub-ducts conveying air to room diffusers.



Distribution plenum



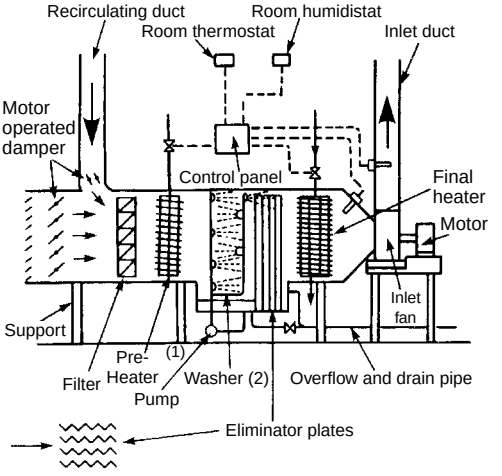
Air processing unit and schematic distribution of air



Diagrammatical layout of central plant only system

Operation of the main air processing or air handling unit:

- Fresh air enters through a louvred inlet and mixes with the recirculated air. Maximum 75% recirculated to minimum 25% fresh air.
- The air is filtered to remove any suspended dust and dirt particles.
- In winter the air is pre-heated before passing through a humidifier. A spray wash humidifier may be used to cool the air up to dew point temperature. If a steam humidifier is used the air will gain slightly in temperature.
- In summer the air can be cooled by a chilled water coil or a direct expansion coil. The latter is the evaporator coil in a refrigeration cycle. Condensation of the air will begin, until at saturation level the air dehumidifies and reduces in temperature. Spray washing will also dehumidify the air.
- Air washers have zig-zag eliminator plates which remove drops of water and any dirt that may have escaped the filter.
- The final heater or reheater is used to adjust the supply air temperature and relative humidity before delivery through a system of insulated ductwork.



Section of main unit for the central plant system

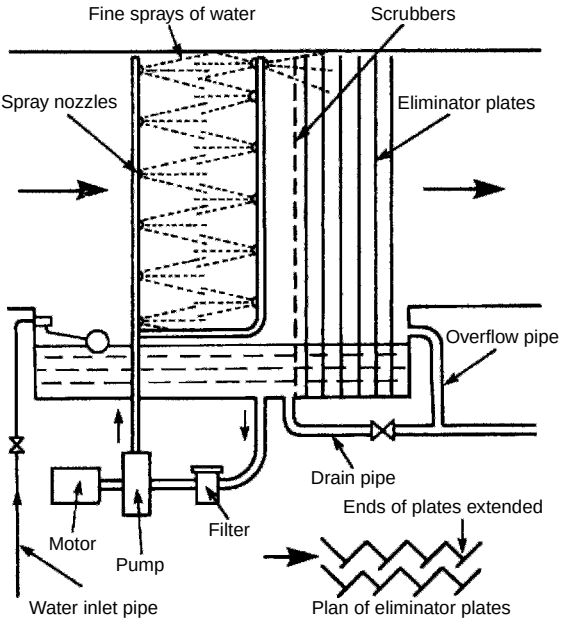
Notes: (1) Pre-heater coil may be used with chilled water as a cooler in the summer months, but two separate coils are usually fitted.

(2) Steam humidifiers are the preferred replacement for spray wash humidifiers. The high temperature steam kills any bacteria.

Depending on the state of the air on entering a spray washer, it can be humidified or dehumidified. Humidification in the presence of moisture is understandable, but dehumidification is less easy to comprehend. It occurs when the spray is at a lower temperature than the air and the dewpoint of the air. In this condition the vapour pressure of the spray will be less than that of moisture in the air and some moisture from the air will transfer into the spray water. Hence, dehumidification.

Washers also remove some of the suspended dirt. Spray water pressure is usually between 200 and 300 kPa. Air velocity through the washer is between 2 and 2·5 m/s. Spray washers must be cleaned periodically and treated to neutralise any bacteria which could be living in the water. Water quality must also be monitored and findings documented. With numerous outbreaks of Legionnaires' disease originating from air conditioning systems, the Health and Safety Executive have identified these spray washers as a possible health risk.

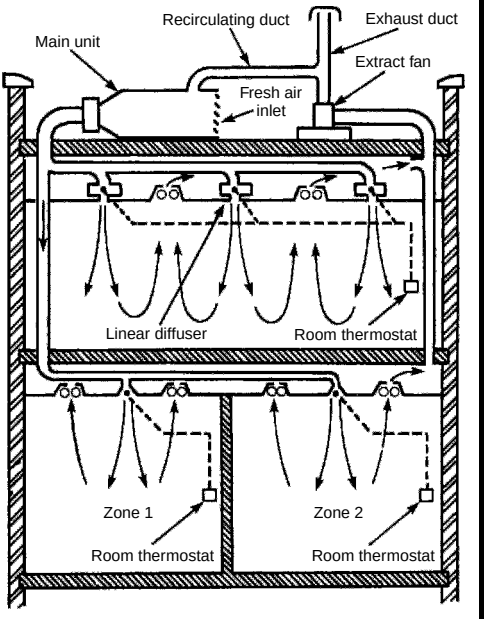
Contemporary air processing units may incorporate steam injection humidifiers, but unlike washers, these should not be located immediately after the cooler coil. Here, the air will be close to saturation or even saturated (100% RH) and unable to accept further moisture. Therefore dry saturated steam at over 200°C is better injected into the air close to its final discharge.



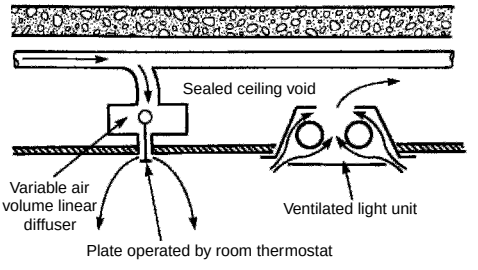
Enlarged section of spray unit

The VAV system has a central air processing unit to produce air at a specified temperature and relative humidity. The conditioned air from the main unit is conveyed in ductwork to ceiling diffusers which incorporate thermostatically controlled actuators. These can change the air volume to suit each room load. In a large room, several of these VAV ceiling units may be controlled by one room thermostat.

Several rooms/zones may have separate thermostats to control the air flow to each room. The inlet fan may have variable pitched impellers operated by compressed air. A pressure switch controls the pitch angle. Air distribution is usually medium to high velocity. The air temperature in each zone can be varied with the heat energy in the delivery air volume, but the system is only suitable for buildings having a fairly evenly distributed cooling load.



Layout of a typical variable air volume system

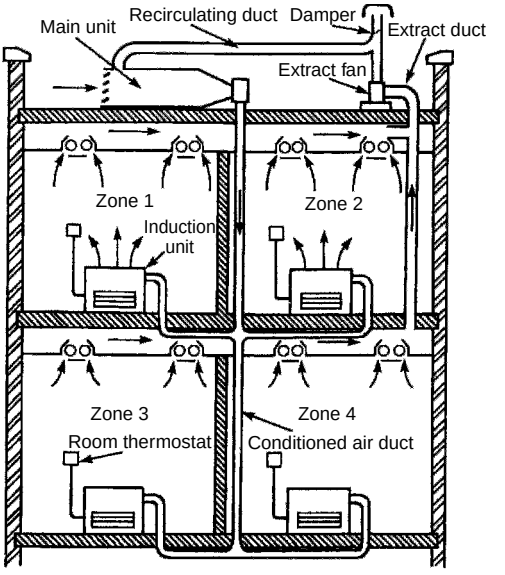


Note: The lighting fittings may require a fire damper

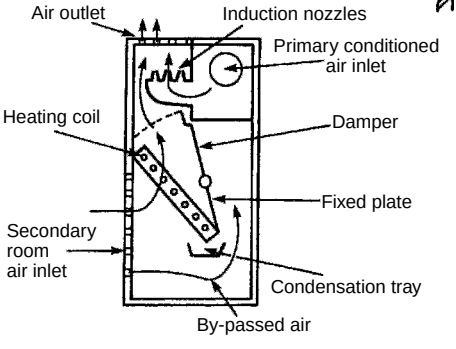
Section through plenum ceiling

Perimeter induction units – usually located under windows – blend primary air from the air processing unit with secondary air from within the room. The high velocity processed air delivery is induced into the unit through restrictive nozzles. This creates a negative pressure in its wake, drawing in the room secondary air for mixing and discharge. A damper regulates the volume of room air passing through a thermostatically controlled heating coil.

These coils may be used with chilled water as cooling coils in the summer months. If heating only is used, the system is known as the `two-pipe induction system'. With the additional two pipes for cooling water, the system is known as the `four-pipe change over induction system'. The latter system gives excellent control of the air temperature in various zones but is very capital intensive, therefore expensive to install.

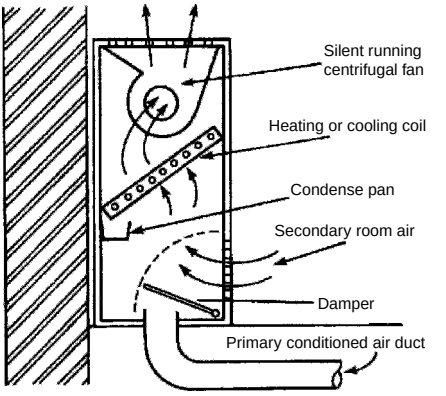


Layout of typical induction system



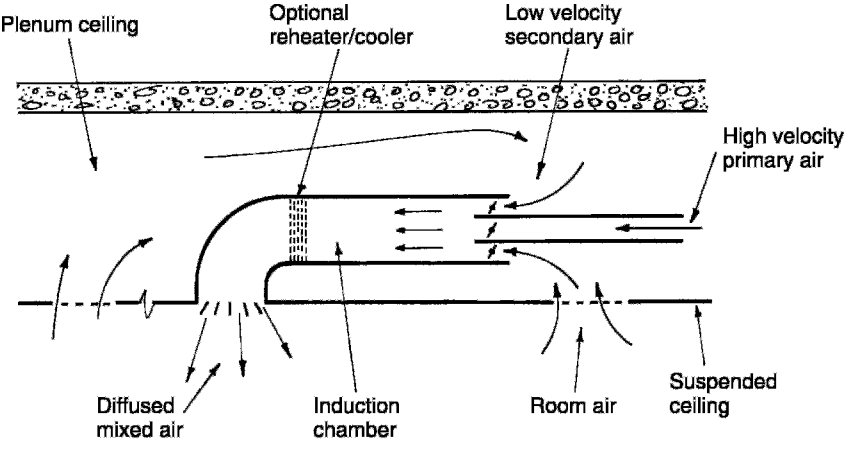
Section through an induction room unit

Fan-coil unit – an alternative discharge unit for application to the induction system shown on the previous page. Instead of nozzle injection of air, a low powered fan is used to disperse a mixture of primary and secondary air after reheating or cooling from an energy exchanger within the unit.



Section through a fan-coil room unit

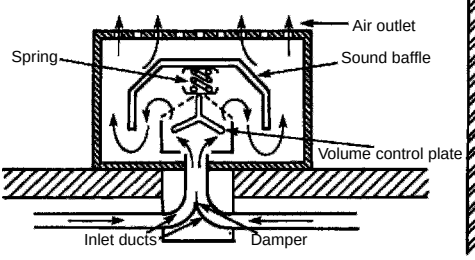
Induction diffuser – another alternative which also uses a blend of recirculated room air with primary air. These locate at the end of branch ductwork and combine a diffuser with a simple primary and secondary air mixing chamber. The high velocity primary air mixes with low velocity secondary air drawn into a plenum ceiling from the room below. Light fitting extract grilles may be used to some advantage in this situation.



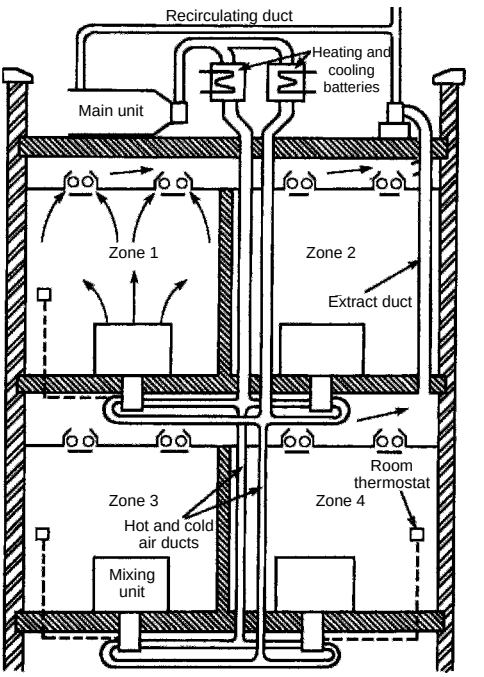
Section through an induction diffuser unit

The dual duct system is another means of providing varying air temperatures to different rooms in the same building. There is no water circulation to peripheral discharge units with terminal reheaters or coolers. This simplifies the plumbing installation as heating and cooling elements for each duct are located in the plant room. However, the system is space consuming and adequate provision must be made in suspended ceilings or raised flooring to accommodate both distribution ducts. The system is most energy economic when heating and cooling elements operate individually. For some of the year this will not be practical and simultaneous delivery of cold and hot air is provided for blending at the point of discharge.

Delivery is at high velocity with hot and cold air regulated by a damper connected to a room thermostat. A control plate in the mixing unit maintains constant air volume. As with all systems of air conditioning, fire dampers are required where the ductwork passes through compartment walls and floors.



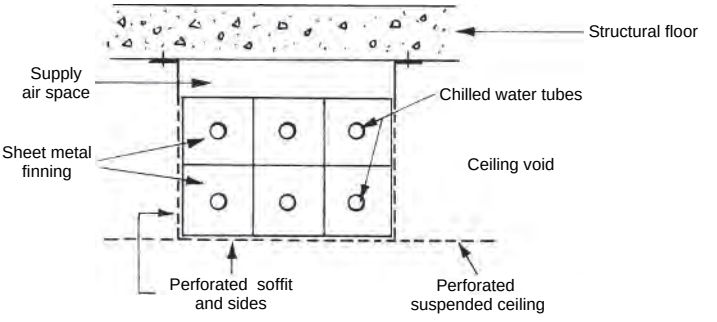
Section through mixing unit



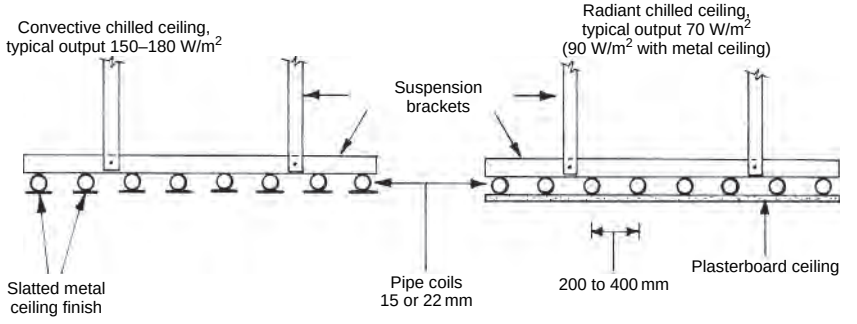
Layout of a typical dual duct system

Chilled beams are usually formed as a bank of finned tubing, arranged in a square or rectangular profile. The tubing conveys chilled water and when encased and secured to the underside of a structural floor, the unit resembles a beam. An outer casing of sheet metal can be used to enclose the coiled pipes and this may be perforated to encourage convection through the bank of finned tubing. A passive cooling effect is by natural convection, but active cooling can be achieved by using a fan driven primary air supply. To conceal the installation, the underside of the box may be finished flush with a perforated suspended ceiling.

Chilled beam – typical output 150 W/m^2 above a ceiling, 350 W/m linear



Chilled ceilings were originally devised with chilled water pipes embedded within the underside of a concrete floor slab. The nominal increase in slab depth justified by no visual intrusion of pipework. This form of radiant cooling has the disadvantage of creating a high thermal mass in the concrete slab, which is slow to respond to thermostatic control. These installations can also produce 'indoor rain' or condensation on the radiant underside of the slab. To prevent the ceiling running wet, a suspended variation is preferred, with the option of an auxiliary or fan driven primary air supply through perforations in the ceiling. These perforations will also increase the convective effect.



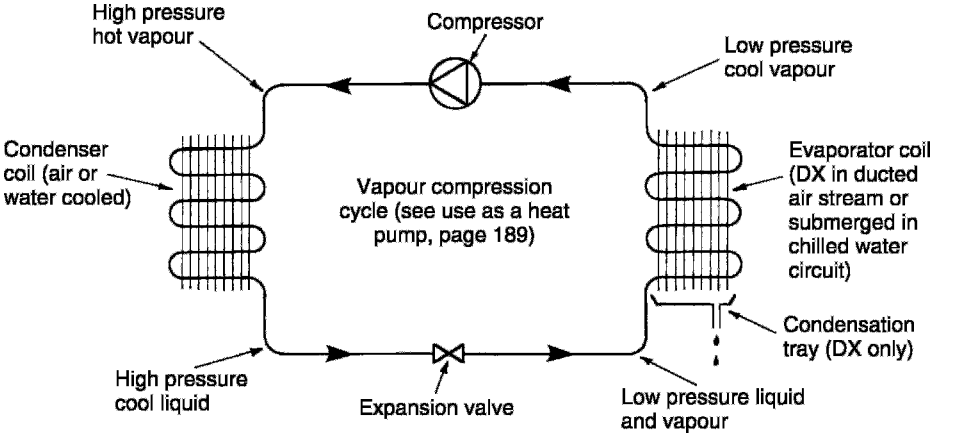
Refrigeration systems are used to:

- Cool water for circulation through chiller coils. Brine may be used as a more efficient alternative to water.
- Directly chill air by suspending the cold evaporator coil in the air stream. When used in this way, the energy exchanger is known as a direct expansion (DX) coil.

The system most suited to air conditioning is the vapour compression cycle. It is a sealed pipe system containing refrigerant, compressor, condenser coil, expansion valve and evaporator coil, i.e. all the basic components of a domestic fridge.

Refrigerants are very volatile and boil at extremely low temperatures of -30 to -40°C. They are also capable of contributing to depletion of the ozone layer when released into the atmosphere. Dichlorodifluoromethane (R12), known as CFC, is used in many existing systems, but banned for new products. Monochlorodifluoromethane (R22), known as HCFC, is less ozone depleting. It is still used, whilst manufacturers research more environmentally friendly alternatives.

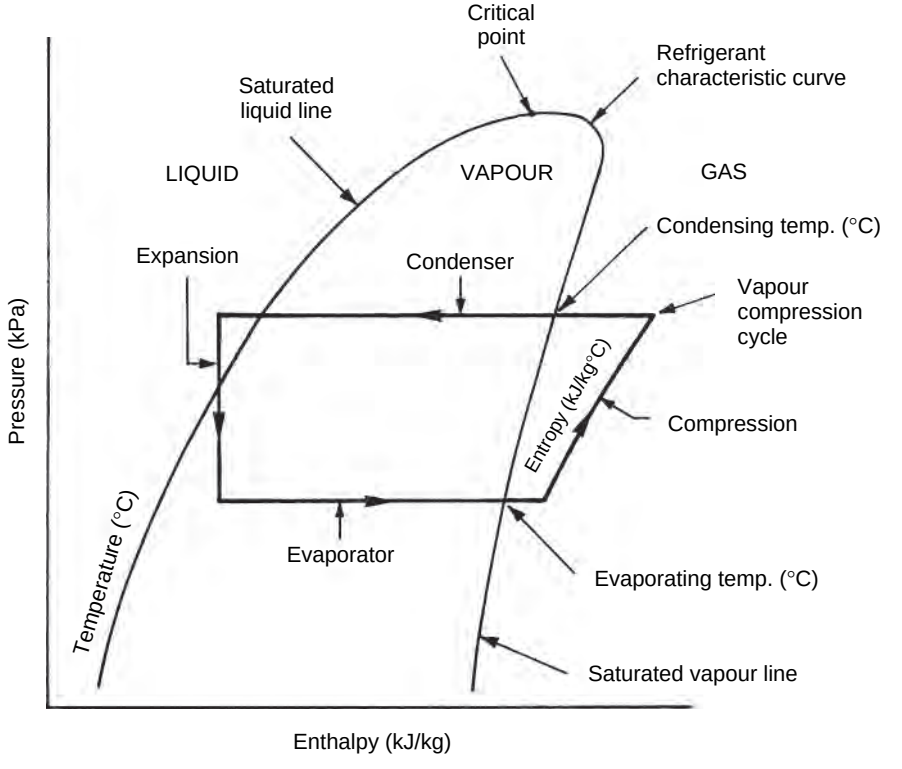
The refrigeration compression and evaporation cycle effects a change of temperature and state in the refrigerant, from liquid to gas and vice versa. Saturation pressure and temperature increase to emit heat at the condenser as heat energy is absorbed by the evaporator. As the liquid refrigerant changes to a gas through the expansion valve, it absorbs considerably more heat than during simple temperature change. This is known as the latent heat of vaporisation.



Pressure enthalpy diagram – graphical representation of a refrigerant showing its total heat content (sensible + latent heat = enthalpy) during liquid, vapour and gaseous states at a given pressure.

Detailed charts are produced by refrigerant manufacturers such as ICI Plc and professional organisations such as the Chartered Institution of Building Services Engineers. The diagram below indicates the outline of these charts. The principal curved line divides the three states of a refrigerant during pressure, temperature and energy change.

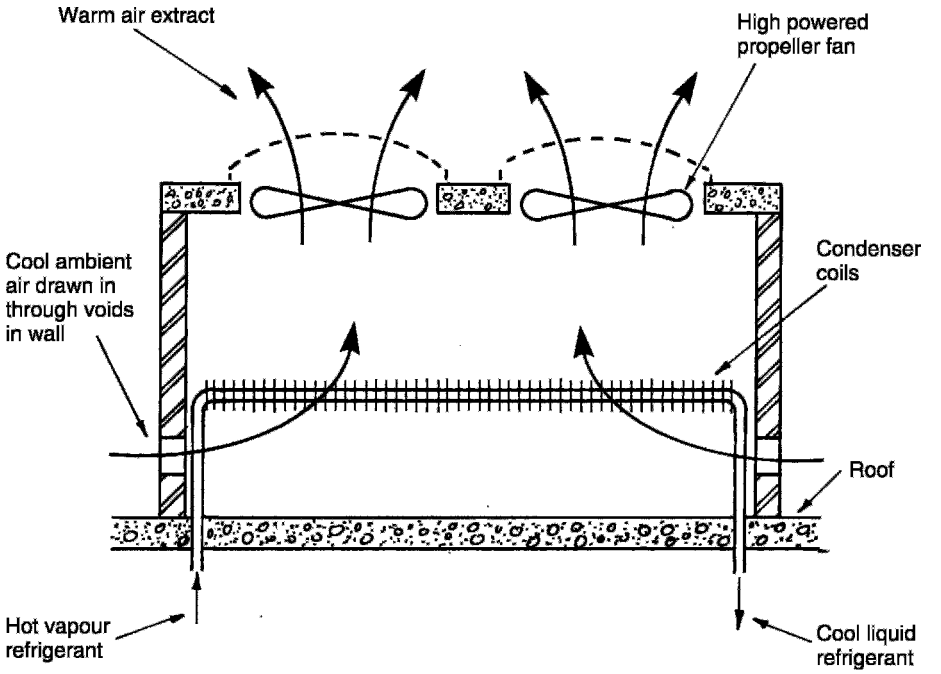
For design purposes, the system operating characteristics can be superimposed on the chart to illustrate changes that occur during the refrigeration cycle. By comparing the system vapour compression cycle on various charts, it is possible to determine the most suitable refrigerant for the purpose.



Typical pressure enthalpy diagram with a vapour compression cycle superimposed

Efficient operation of refrigeration systems depends to a large extent on maintaining condenser temperature at an optimum level. This is necessary for correct reaction of the refrigerant. The cooling medium can be water or air. Water is more effective, but for practical purposes and health issues (see page 205), air cooling is becoming more widely used.

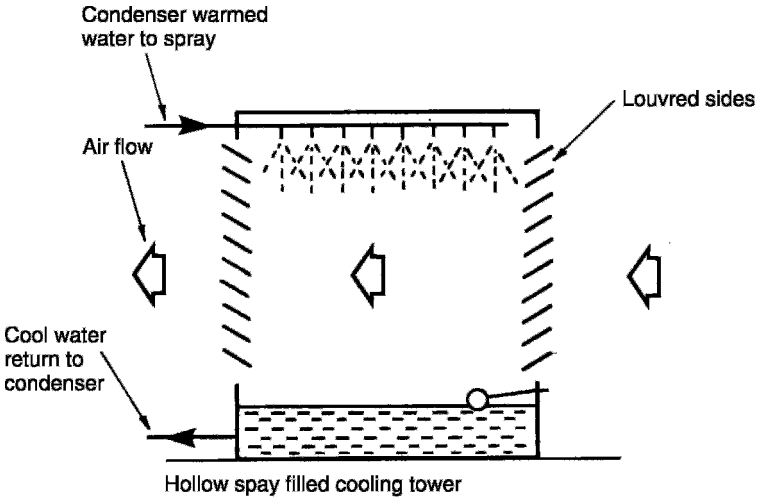
The condenser coil on a domestic fridge is suspended at the back of the unit and exposed to ambient air to cool. This same principle can be applied to small packaged and portable air conditioning units, possibly with the addition of a fan to enhance the cooling effect. Larger-scale air conditioning installations have several high powered fans to cool the condensers. These fans can be mounted horizontally or vertically to draw high velocity air through the condenser coils.



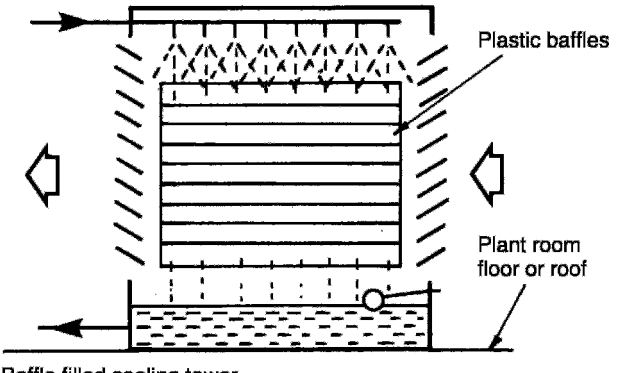
Fan cooled condenser

Natural draught water cooling can take many forms. The simplest and most inexpensive is a pond. Cooled water is drawn from one end and warm return water pumped into the other. Spray ponds are more efficient and may incorporate ornamental fountains as part of the process. Both have a tendency to accumulate debris and will require regular attention.

More common are evaporative atmospheric cooling towers. These are usually located on the building roof or within the roof structure plant room. Wall construction is louvred to permit crossflow of air. Internally the tower is either hollow or plastic baffled to increase the wetted contact area. Warm water from cooling the condenser is discharged through a bank of high level sprays to cool as it descends through the air draught. It is then recirculated to the condenser.



Hollow spay filled cooling tower

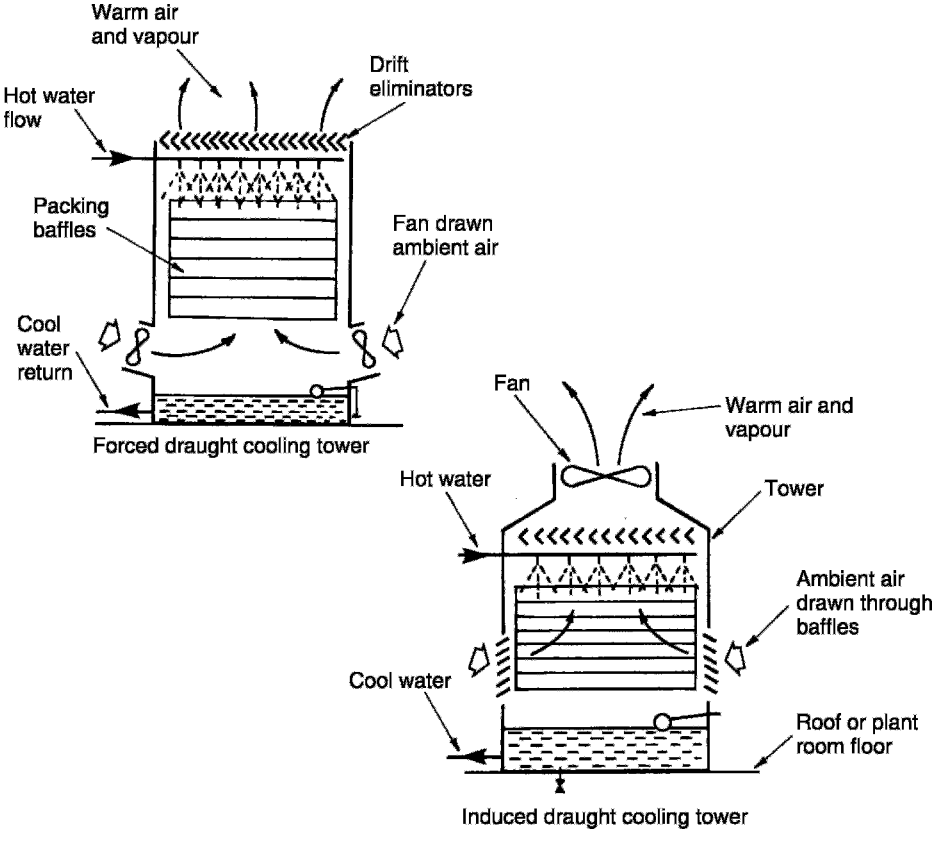


Baffle filled cooling tower

Mechanical fan draught cooling provides absolute control over the air supply, operating independently of fickle weather and wind direction. Fan draught cooling towers are of two types:

1. Forced draught – similar in construction and operating principle to the natural draught tower, but with one or more low level fans to force air through the tower.
2. Induced draught – a large high level fan draws or induces air flow through the tower. The relatively large single fan is more economic in use and less likely to generate system noise and vibration.

Note: All water cooling towers have become notorious as potential breeding areas for bacteria such as that associated with Legionnaires' disease. Therefore, towers must be maintained regularly and the water treated with a biocide, with regard to Workplace (Health, Safety and Welfare) Regulations 1992.



Packaged Air Conditioning Systems – 1

Packaged air conditioning systems are factory manufactured units, delivered to site for direct installation. They contain a vapour compression cycle refrigeration system, using the evaporator for cooling and the condenser for heating, with fan delivery of the processed air. They are available in a wide range of power capacity, fan output, refrigeration and heating load for adaptation to various building types and situations.

Small- to medium-sized buildings are best suited to these systems as it would be too costly and impractical to provide numerous units for use in multi-roomed large buildings. The smallest units (1–3 kW) are portable and free standing, simply plugging into an electrical wall socket. Larger, fixed units (generally 10–60 kW, but available up to 300 kW) can be unsightly and difficult to accommodate. These may be located in a store room and have short ductwork extensions to adjacent rooms.

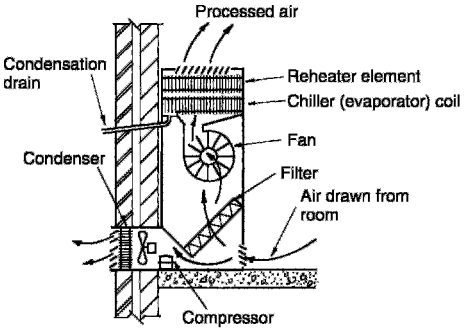
Packages contain all the processes of conventional air handling units, with the exception of a steam or water humidifier. Humidification is achieved with condensation from the direct expansion (DX) refrigeration coil suspended in the air intake.

For summer use, the cold (DX) coil cools incoming and recirculated air. The hot condenser coil is fan cooled externally. For winter use, the refrigeration cycle is reversed by a changeover valve to become a heat pump – see page 216. Now the cold incoming air is warmed or pre-heated through the hot condenser coil and may be further heated by an electric element or hot water coil at the point of discharge.

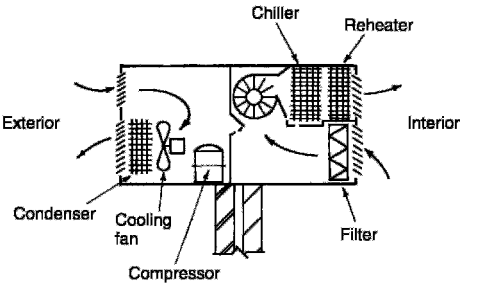
System types:

- Self-contained (single) package.
- Split (double) package.

Self-contained (single) package – suitable for relatively small rooms, e.g. shops, restaurants and classrooms. May be free standing or attached to the structure.

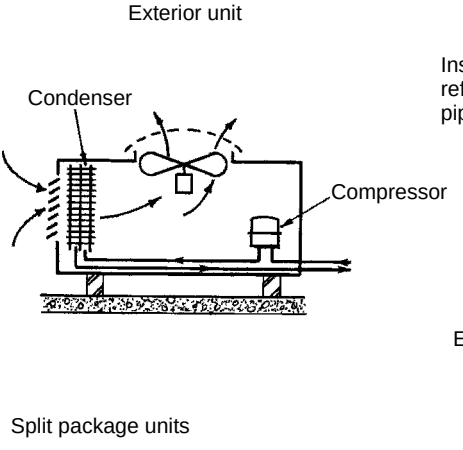


Single duct packaged unit



Single package wall opening unit

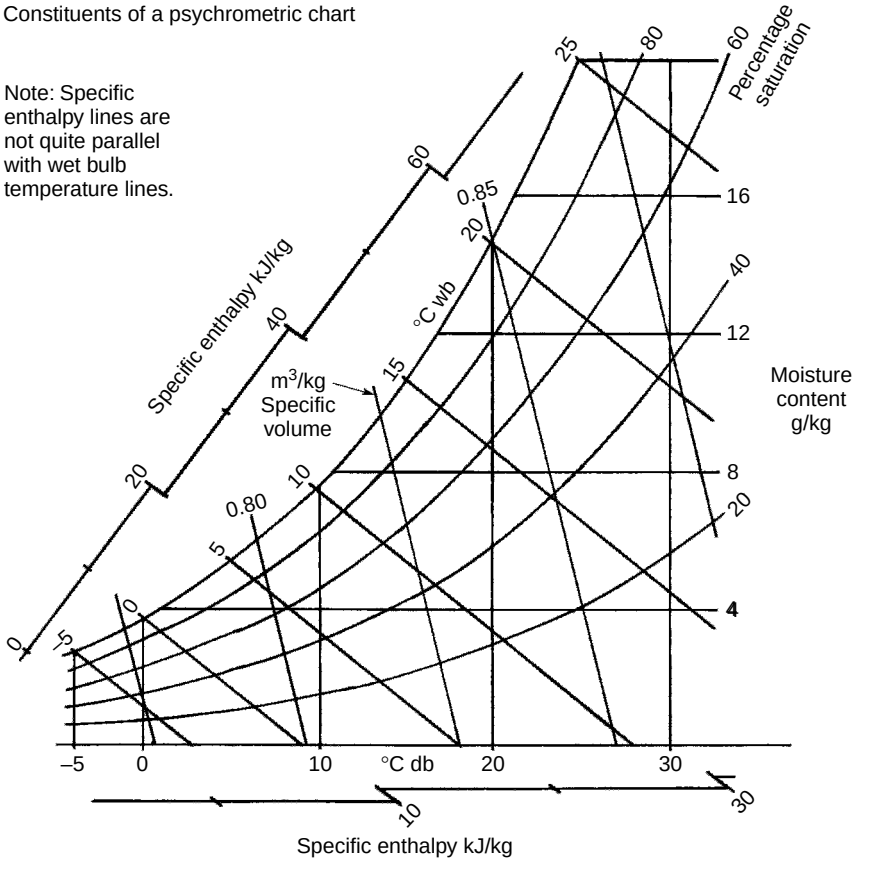
Split (double) package – two separate units. One contains fan, filter, evaporator and expansion valve for interior location. The other contains condenser, fan and compressor for external location. The two link by refrigeration pipework. This has the advantage that one external unit can serve several interior units.



Split package units

Psychrometry – the science of moist air conditions, i.e. the characteristics of mixed air and water vapour. This can be calculated or design manuals consulted for tabulated information. Graphical psychrometric details are also available for simplified presentation of data. The chart outlined below is based on the calculated interrelationship of air properties at varying temperatures and conditions. In more detailed format, reasonably accurate design calculations can be applied. These are based on the processes shown plotted on the next page.

Constituents of a psychrometric chart

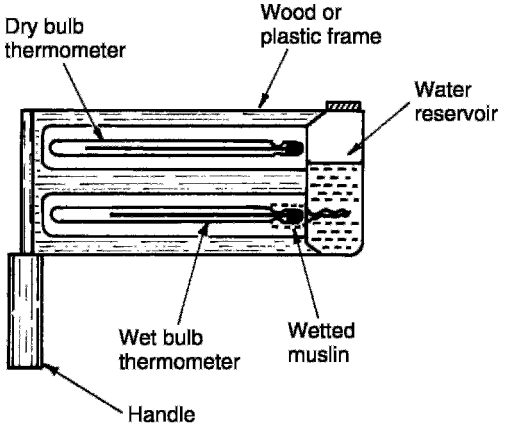


The above diagram represents only the outline structure of a psychrometric chart. For accurate applications and calculations, detailed charts are available from the publications section of the Chartered Institution of Building Services Engineers. Contact, www.cibse.org.

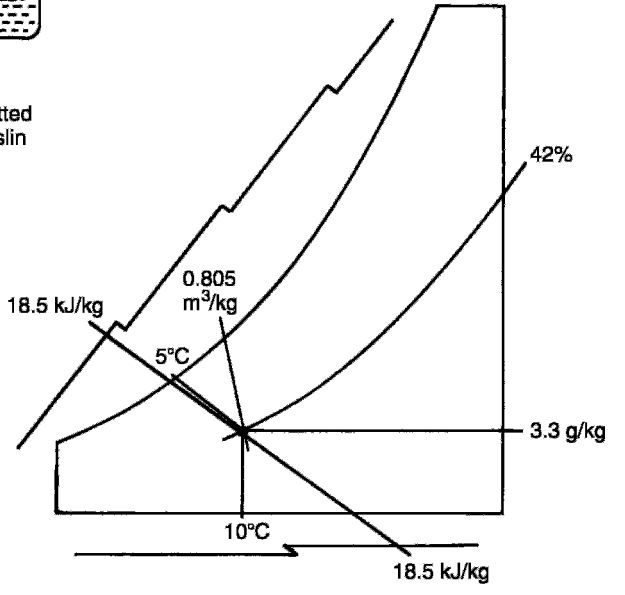
To locate a representative air condition on the psychrometric chart, two properties of the air must be known. The easiest coordinates to obtain are the dry and wet bulb temperatures. These can be measured from a sling psychrometer, also known as a whirling or sling hygrometer. Two mercury-in-glass thermometers are mounted in a frame for rotation about the handle axis. One thermometer bulb has a wetted muslin wick. After rotation, the wet bulb temperature will be lower than the dry bulb due to the evaporation effect of moisture from the muslin. The extent of evaporation will depend on the moisture content of the air.

For example, a sling psychrometer indicates 10°C db and 5°C wb temperatures. From the chart the following can be determined:

Percentage saturation = 42%
Moisture content = 3·3 g/kg dry air
Specific volume = 0·805 m^3/kg
Specific enthalpy = 18·5 kJ/kg



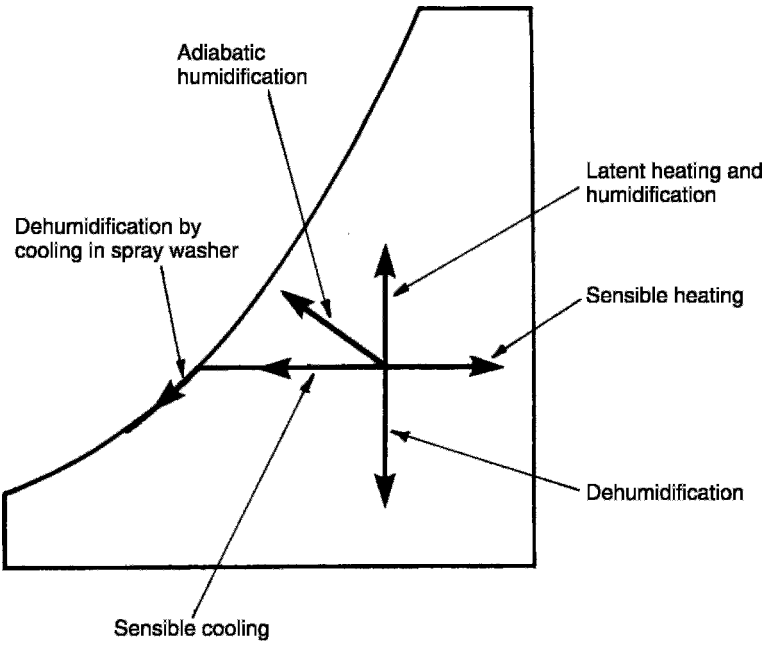
Sling psychrometer



Psychrometric coordinates

Treatment of air is based on heating, cooling, humidification and dehumidification. These processes can be represented by lines drawn on the psychrometric chart.

- Heating (sensible) is depicted by a horizontal line drawn left to right. Dry bulb temperature increases with no change in moisture content, but there is a reduction in percentage saturation.
- Heating (latent) is the effect of steam humidification and is represented by a rising vertical line. Dry bulb temperature remains the same, moisture content and percentage saturation increase.
- Cooling (sensible) is depicted by a horizontal line drawn right to left. Dry bulb temperature decreases with no change in moisture content. Cooling by water spray humidifier is represented by an incline following the wet bulb temperature line. This is known as adiabatic humidification. Both cooling processes show an increase in percentage saturation.
- Dehumidification is shown with a descending vertical line. Moisture content and percentage saturation decrease.

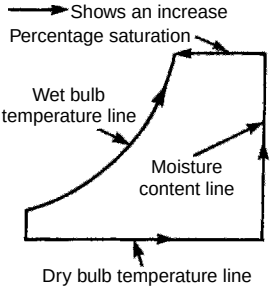


Psychrometric processes

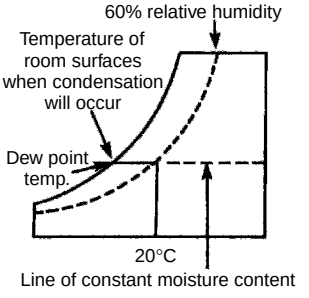
Sensible heating of air may reduce its percentage saturation or relative humidity to an unacceptable level, i.e. <30%. Conversely, sensible cooling may increase the percentage saturation or humidity to an unacceptable level, i.e. >70%.

Applications:

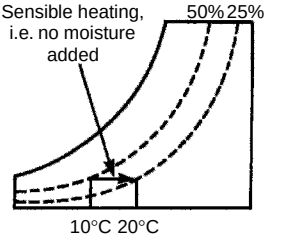
1. Air enters the air handling unit at 5°C db with an RH of 60%. Conditioned air is required at 20°C db with an RH of 50%. The air is pre-heated to 18·5°C db, cooled to 9°C dew point temperature (dry and wet bulb temperatures identical) and reheated to 20°C db (see lower diagram, centre).
2. Air enters the a.h.u. at 30°C db with an RH of 70%. Conditioned air is required at 20°C db with an RH of 50%. The air is cooled to 9°C dew point temperature and reheated to 20°C db (see lower diagram, right).



Use of psychrometric chart

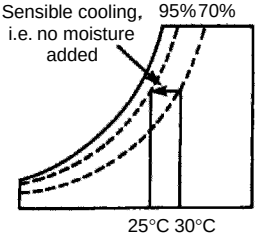


Condensation on room surfaces



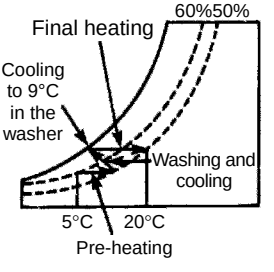
If the air is heated from 10°C to 20°C the RH = 25%

Heating of air without adding moisture

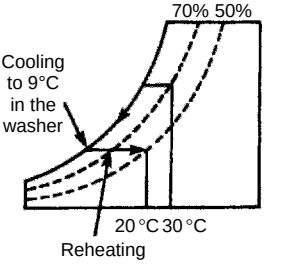


If the air is cooled from 30°C to 25°C the RH = 95%

Cooling of air without dehumidification



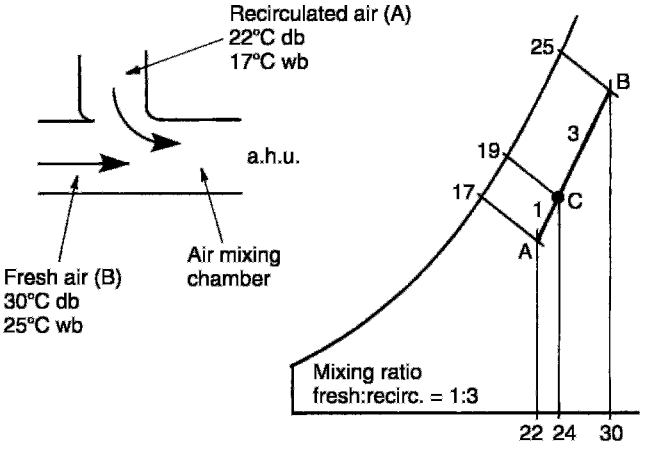
Humidifying by pre-heating, washing and final heating



Dehumidifying by cooling, washing and reheating

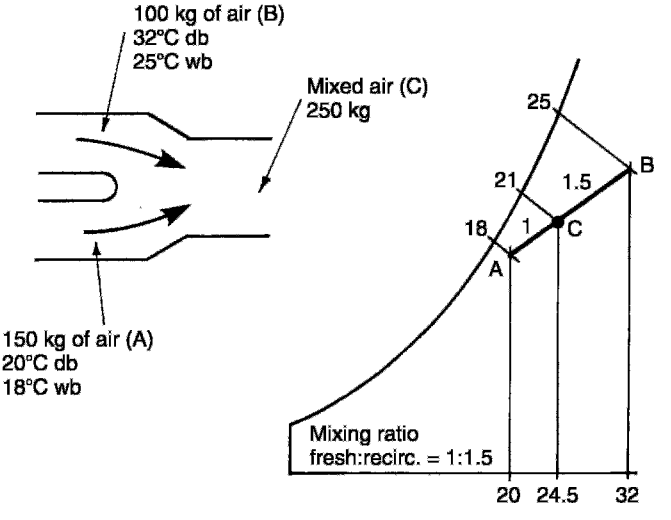
Mixing of two airstreams frequently occurs when combining fresh air with recirculated air from within the building. The process can be represented on a psychrometric chart by drawing a straight line between the two conditions and calculating a point relative to the proportions of mass flow rates.

Example 1:



Mixed air condition (C) is found on straight line linking (A) and (B) proportioned 1:3, i.e. 24°C db, 19°C wb, 63% RH and 12g/kg m.c.

Example 2:

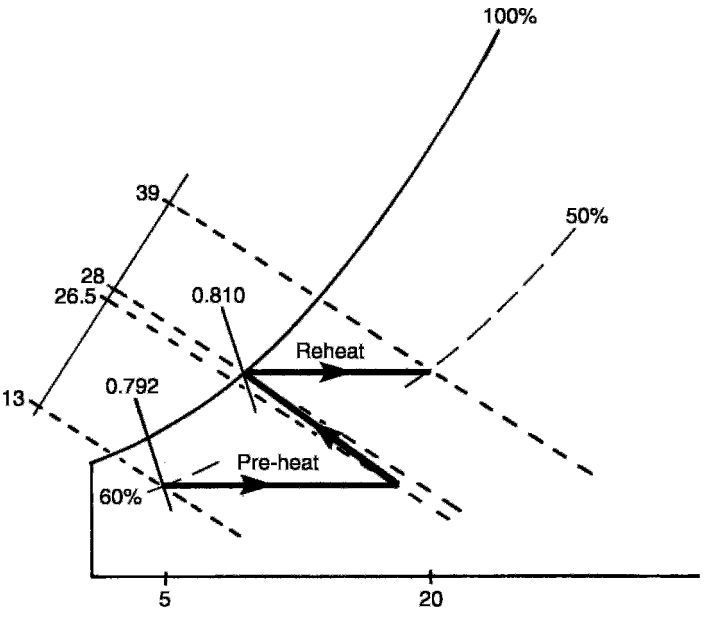


Mixed air (C) = 24.5°C db, 21°C wb, 72% RH and 14 g/kg m.c.

The calculation below relates to the example on page 211, where cool intake air at 5°C db, 60% RH is conditioned to 20°C db, 50% RH.

Applied to an office of 2400 m^3 volume, requiring three air changes per hour, the quantity of air (Q) delivered will be:

$$Q = \frac{\text{Volume} \times \text{Air changes per hour}}{3600} = \frac{2400 \times 3}{3600} = 2\ m^3/s$$



Humidifying by pre-heating, washing and final heating

Pre-heater enthalpy = 26·5 – 13 = 13·5 kJ/kg. Specific volume = 0·792 m^3/kg

Reheater enthalpy = 39 – 28 = 11 kJ/kg. Specific volume = 0.810 m^3/kg

Pre-heater

Specific volume converted to kg/s: 2·0 m^3/s ÷ 0·792 m^3/kg = 2·53 kg/s

Pre-heater rating: 2·53 kg/s × 13·5 kJ/kg = 34·2 kW

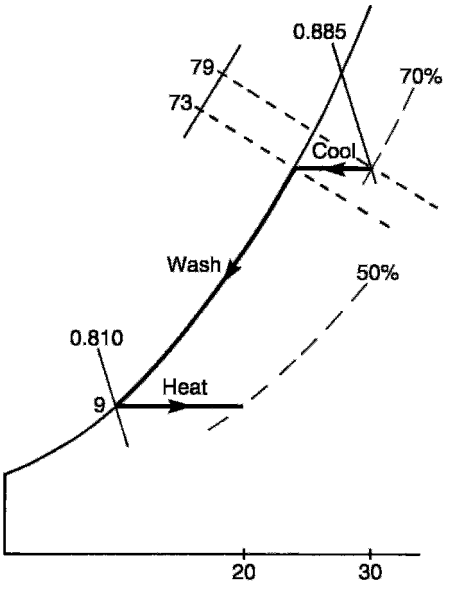
Reheater

Specific volume converted to kg/s: 2·0 m^3/s ÷ 0·810 m^3/kg = 2·47 kg/s

Reheater rating: 2·47 kg/s × 11 kJ/kg = 27·2 kW

The calculation below relates to the example on page 211, where warm intake air at 30°C db, 70% RH is conditioned to 20°C db, 50% RH.

With reference to the situation given on the previous page, the quantity of air delivered will be taken as 2 m^3/s.



Dehumidifying by cooling, washing and reheating

Chiller enthalpy = 79 – 73 = 6 kJ/kg. Specific volume = 0·885 m^3/kg

Specific volume converted to kg/s: 2·0 $m^3/s \div 0{\cdot}885\ m^3/kg$ = 2·26 kg/s

Chiller rating: 2·26 kg/s × 6 kJ/kg = 13·6 kW

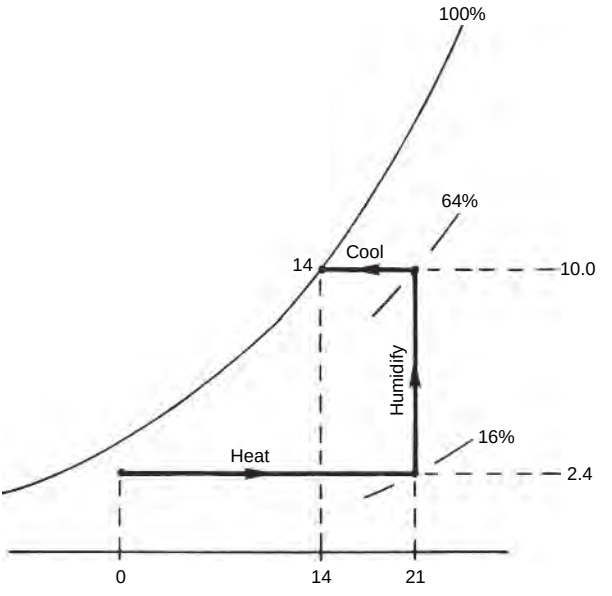
Note: Calculations on this and the preceding page assume 100% efficiency of plant. This is unrealistic, therefore energy exchangers should be over-rated to accommodate this.

E.g. If the chiller is 80% efficient, it will be rated:

13.6 × 100/80 = 17 kW

Internal surface condensation can be minimised by providing a balance between heating, ventilation and insulation. Inadequate, intermittent or partial heating can produce a situation where the internal surfaces are colder than adjacent air temperatures. This will attract dampness to the surfaces from the moisture in the warmer air. A low rate of ventilation will also encourage a high level of humidity.

As shown in the diagram, external and internal environmental conditions can be plotted on a psychrometric chart to predict the risk of surface condensation.



E.g.

External air conditions:

0°C dry bulb temperature
2.4 g/kg moisture content

Internal air conditions:

Air warmed to 21°C dry bulb temperature
Supply air moisture content remains at 2.4 g/kg
RH or percentage saturation reduces to 16%
Internal activities add 7.6 g/kg to moisture content (10 g/kg total)
RH or percentage saturation increases to 64%

Condensation is shown to occur at 14°C or below. Otherwise known as a dewpoint temperature of 14°C db and 14°C wb at 100% RH.

A heat pump is in principle a refrigeration cycle. It differs in application, extracting heat from a low temperature source and upgrading it to a higher temperature for heat emission or water heating. The low temperature heat source may be from water, air or soil which surrounds the evaporator.

A heat pump must be energy efficient; it must generate more power than that used to operate it. A measure of theoretical coefficient of performance (COP) can be expressed as:

$$COP = T_c / T_c - T_e$$

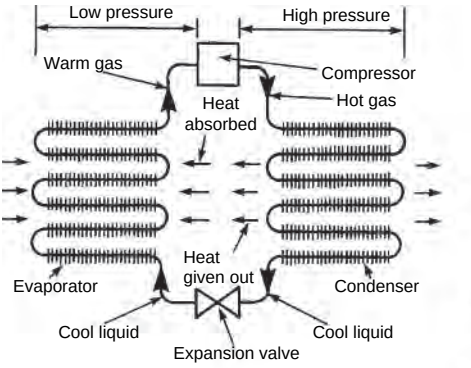
where: T_c = condenser temperature based on degrees Kelvin (0°C = 273 K)

T_e = evaporator temperature based on degrees Kelvin

E.g. T_c = 60°C, Te = 2°C.

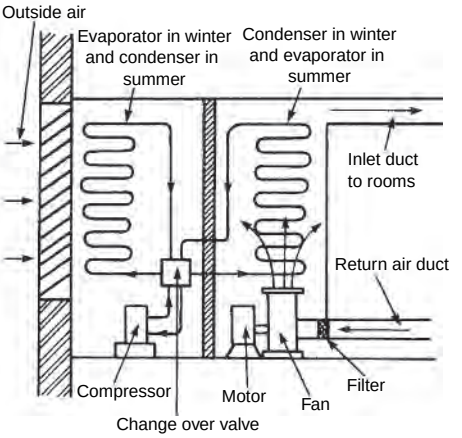
$$COP = \frac{60 + 273}{(60 + 273) - (2 + 273)} = 5{\cdot}74$$

i.e. 5·74 kW of energy produced for every 1 kW absorbed. Allowing for efficiency of equipment and installation, a COP of 2 to 3 is more likely.



Note:- The flow of the refrigerant can be reversed so that the building is warmed in winter and cooled in summer

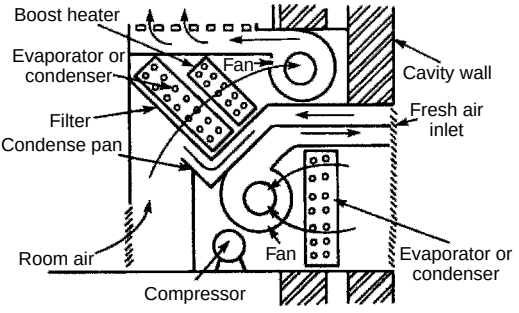
Principles of operation of the heat pump



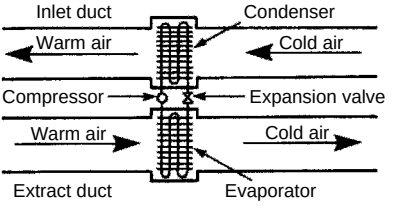
The heat pump used for cooling in summer and warming in winter

Heat pump units are available as large items of plant that can be used to warm a whole building. However, small self-contained units are more common. These are usually located under window openings for warm and cool air distribution in winter and summer respectively.

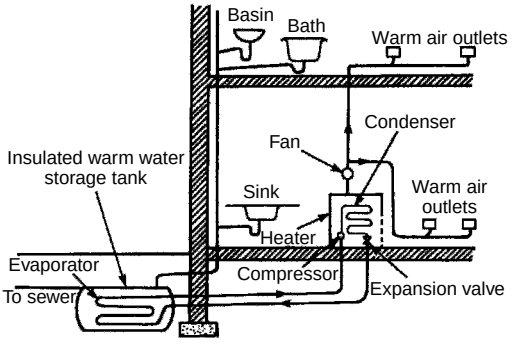
To transfer the warmth in stale extract duct air, water may be circulated through coils or energy exchangers in both the extract and cool air intake ducts. This is known as a run-around coil. Using water as an energy transfer medium is inexpensive but limited in efficiency. Use of a refrigerant is more effective, with an evaporator coil in the warm extract duct and a condenser coil in the cold air inlet duct.



Unit heat pump fixed below window



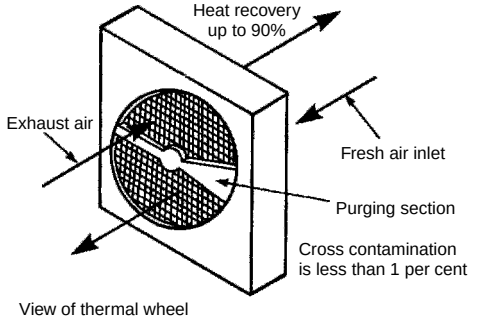
Heat pump used for heat recovery



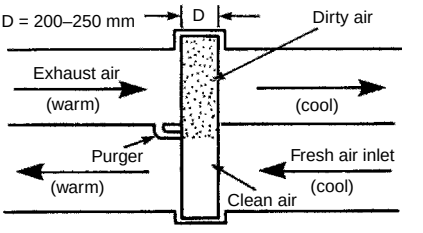
Heat pump used for extracting heat from warm waste water

Heat energy in warm waste water from sanitary fittings may be retrieved and used to supplement space heating by using a heat pump. An insulated tank buried below ground receives the waste water before it flows to the sewer. Heat energy is extracted through an evaporator inside the tank.

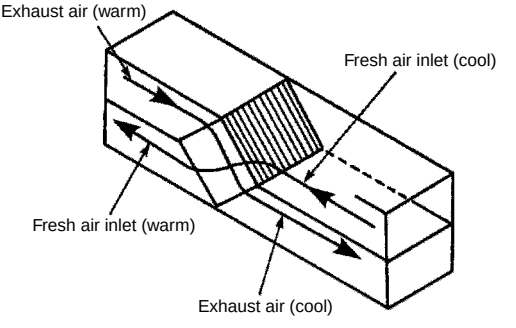
The concept of a thermal or heat wheel was devised about 50 years ago by Carl Munter, a Swedish engineer. Wheels range from 600 mm to 4 m in diameter, therefore sufficient space must be allowed for their accommodation. They have an extended surface of wire mesh or fibrous paper impregnated with lithium chloride. Lithium chloride is an effective absorbent of latent heat energy in the moisture contained in stale air. A low power (700 W) electric motor rotates the wheel at an angular velocity of 10–20 rpm. Heat from the exhaust air transfers to the inlet air and the purging section extracts the contaminants. Efficiency can be up to 90%.



View of thermal wheel



Section through thermal wheel



Heat recovery duct

The heat recovery duct or plate heat exchanger has warm exhaust air separated from the cool inlet air by metal or glass vanes. Heat from the exhaust vanes is transferred to the inlet vanes to warm the incoming air. Ducts must be well insulated to conserve energy and to reduce condensation. Condensation should be drained at the base of the unit. Efficiency is unlikely to exceed 50%.

Buildings are designed with the intention of providing a comfortable internal environment. To achieve this efficiently, many incorporate air conditioning and ventilation systems. Misuse of some of the system equipment may cause the following health hazards:

- Legionnaires' disease.
- Humidifier fever (see next page).
- Sick building syndrome (see next page).

Legionnaires' disease – obtained its name from the first significant outbreak that occurred during an American Legionnaires' convention in Philadelphia, USA, in 1976. The bacterial infection was contracted by 182 people; it has similar symptoms to pneumonia. Of these, 29 died. Subsequently, numerous outbreaks have been identified worldwide. They are generally associated with hot water systems (see page 71) and air conditioning water cooling towers.

The organisms responsible occur naturally in swamps and similar humid conditions. In limited numbers they are harmless, but when concentrated they contaminate the water in which they live. If this water is suspended in the air as an aerosol spray, it can be inhaled to establish lung disease in susceptible persons.

Areas for concern – water systems with a temperature between 20°C and 60°C, as the optimum breeding temperature of the bacteria is about 40°C; water cooling towers, particularly the older type with coarse timber packing in dirty/dusty atmospheres, e.g. city centres and adjacency with building sites; contaminated spray dispersing in the atmosphere can be inhaled by people in the locality or it may be drawn into a ventilation inlet and distributed through the ductwork; spray humidifiers in air handling units are also possible breeding areas – the water in these should be treated with a biocide or they should be replaced with steam humidifiers.

People at risk – the elderly, those with existing respiratory problems, heavy smokers and those in a generally poor state of health. Nevertheless, there have been cases of fit, healthy, young people being infected.

Solution – abolition of wet cooling towers and replacement with air cooled condensers. Use of packaged air conditioning with air cooling. Documented maintenance of existing wet cooling towers, i.e. regular draining and replacement of water, cleaning of towers and treatment of new water with a biocide.

Ref: Workplace (Health, Safety and Welfare) Regulations 1992.

Humidifier fever – this is not an infection, but an allergic reaction producing flu-like symptoms such as headaches, aches, pains and shivering. It is caused by micro-organisms which breed in the water reservoirs of humidifiers whilst they are shut down, i.e. weekends or holidays. When the plant restarts, concentrations of the micro-organisms and their dead husks are drawn into the airstream and inhaled. After a few days' use of the plant, the reaction diminishes and recommences again after the next shutdown. Water treatment with a biocide is a possible treatment or replacement with a steam humidifier.

Sick building syndrome – this is something of a mystery as no particular cause has been identified for the discomfort generally attributed to this disorder. The symptoms vary and can include headaches, throat irritations, dry or running nose, aches, pains and loss of concentration. All or some may be responsible for personnel inefficiency and absenteeism from work. Whilst symptoms are apparent, the causes are the subject of continued research. Some may be attributed to physical factors such as:

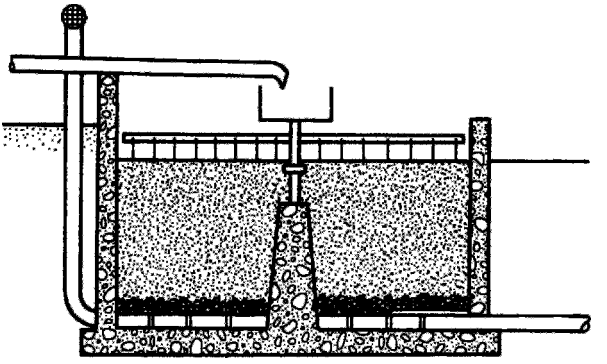
- Noise from computers, machinery, lighting or ducted air movement.
- Strobing from fluorescent strip lights.
- Static electricity from computer screens, copiers, etc.
- Fumes from cleaning agents.
- Glare from lighting and monitors.
- Unsympathetic internal colour schemes.
- Carpet mites.

Other factors are psychological:

- Lack of personal control over an air conditioned environment.
- No direct link with the outside world, i.e. no openable windows.
- Disorientation caused by tinted windows.
- Working in rooms with no windows.
- Dissatisfaction with air conditioning does not provide the ideal environment.

More apparent may be lack of maintenance and misuse of air conditioning plant. Energy economising by continually recirculating the same air is known to cause discomfort for building occupants. The research continues and as a result of sick building syndrome, new building designs often favour more individual control of the workplace environment or application of traditional air movement principles such as stack effect.

7 DRAINAGE SYSTEMS, SEWAGE TREATMENT AND REFUSE DISPOSAL

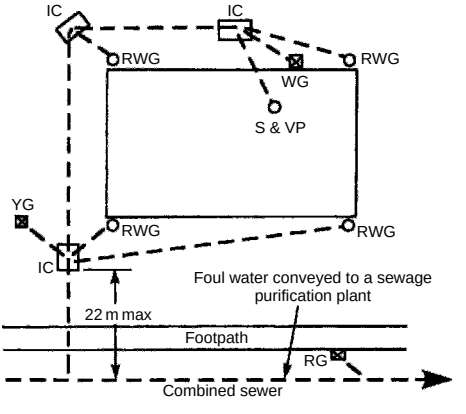


COMBINED AND SEPARATE SYSTEMS
PARTIALLY SEPARATE SYSTEM
RODDING POINT SYSTEM
SEWER CONNECTION
DRAINAGE VENTILATION
UNVENTILATED SPACES
DRAIN LAYING
MEANS OF ACCESS
BEDDING OF DRAINS
DRAINS UNDER OR NEAR BUILDINGS
JOINTS USED ON DRAIN PIPES
ANTI-FLOOD DEVICES
GARAGE DRAINAGE
DRAINAGE PUMPING
SUBSOIL DRAINAGE
TESTS ON DRAINS
SOAKAWAYS
CESSPOOLS AND SEPTIC TANKS
DRAINAGE FIELDS AND MOUNDS
DRAINAGE DESIGN
WASTE AND REFUSE PROCESSING

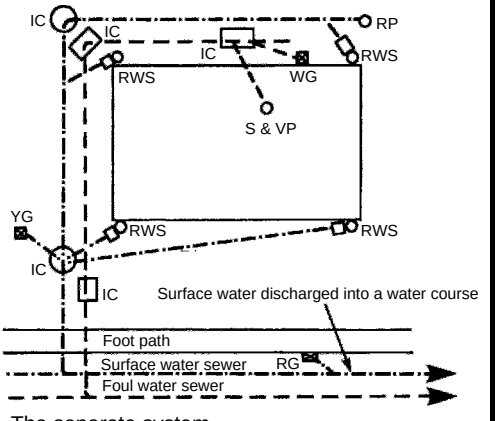
The type of drainage system selected for a building will be determined by the local water authority's established sewer arrangements. These will be installed with regard to foul water processing and the possibility of disposing surface water via a sewer into a local water course or directly into a soakaway.

Combined system – this uses a single drain to convey both foul water from sanitary appliances and rainwater from roofs and other surfaces to a shared sewer. The system is economical to install, but the processing costs at the sewage treatment plant are high.

Separate system – this has foul water from the sanitary appliances conveyed in a foul water drain to a foul water sewer. The rainwater from roofs and other surfaces is conveyed in a surface water drain into a surface water sewer or a soakaway. This system is relatively expensive to install, particularly if the ground has poor drainage qualities and soakaways cannot be used. However, the benefit is reduced volume and treatment costs at the processing plant.



The combined system



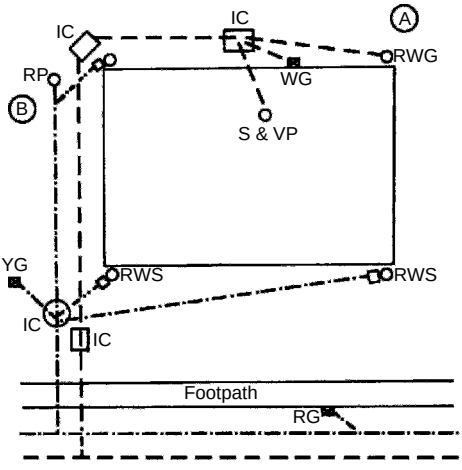
The separate system

Key:

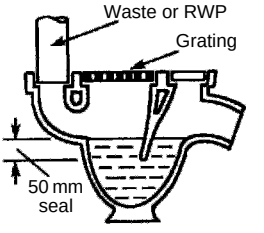
IC = Inspection chamber	RWG = Rainwater gully
WG = Waste gully	RG = Road gully
YG = Yard gully	RWS = Rainwater shoe
RP = Rodding point	S & VP = Soil and vent pipe (discharge stack)

Partially separate system – most of the rainwater is conveyed by the surface water drain into the surface water sewer. For convenience and to reduce site costs, the local water authority may permit an isolated rainwater inlet to be connected to the foul water drain. This is shown with the rainwater inlet at A connected to the foul water inspection chamber. Also, a rodding point is shown at B. These are often used at the head of a drain, as an alternative to a more costly inspection chamber.

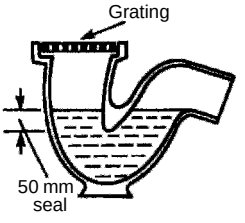
A back inlet gully can be used for connecting a rainwater down pipe or a waste pipe to a drain. The bend or trap provides a useful reservoir to trap leaves. When used with a foul water drain, the seal prevents air contamination. A yard gully is solely for collecting surface water and connecting this with a drain. It is similar to a road gully, but smaller. A rainwater shoe is only for connecting a rainwater pipe to a surface water drain. The soil and vent pipe or discharge stack is connected to the foul water drain with a rest bend at its base. This can be purpose made or produced with two 135° bends. It must have a centre-line radius of at least 200 mm.



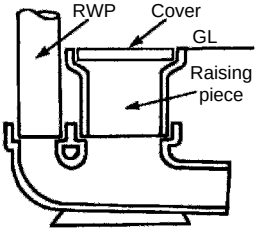
The partially separate system



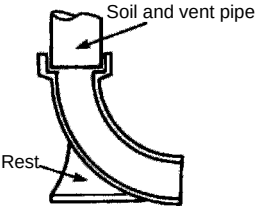
Waste of rainwater gully



Yard gully

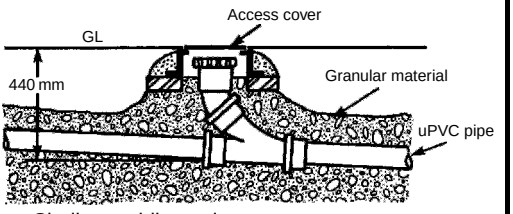


Rainwater shoe

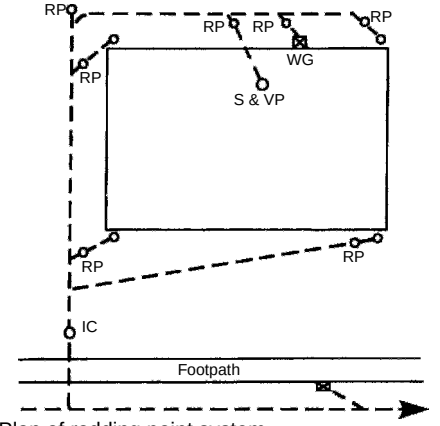


Rest bend

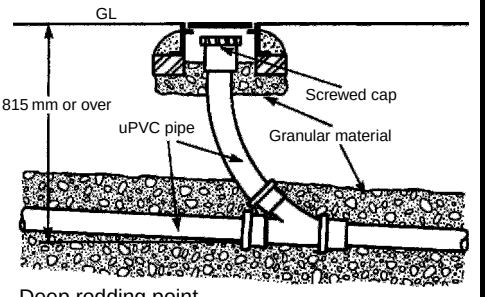
Rodding points or rodding eyes provide a simple and inexpensive means of access at the head of a drain or on shallow drain runs for rodding in the direction of flow. They eliminate isolated loads that manholes and inspection chambers can impose on the ground, thus reducing the possibility of uneven settlement. The system is also neater, with less surface interruptions. Prior to installation, it is essential to consult with the local authority to determine whether the system is acceptable and, if so, to determine the maximum depth of application and any other limitations on use. As rodding is only practical in one direction, an inspection chamber or manhole is usually required before connection to a sewer.



Shallow rodding point



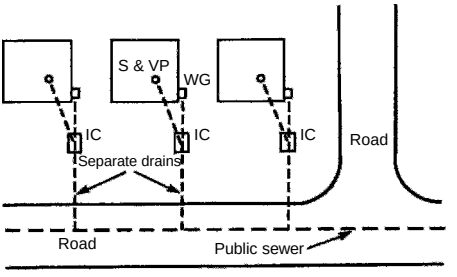
Plan of rodding point system



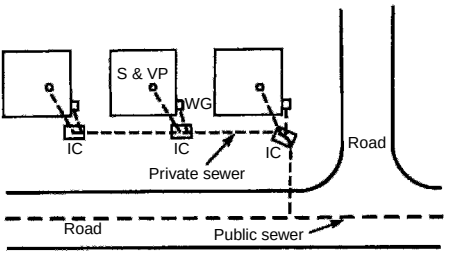
Deep rodding point

Refs: Building Regulations, Approved Documents H1: Foul water drainage and H3: Rainwater drainage.
BS EN 752: Drain and sewer systems outside buildings.

Connections between drains and sewers must be obliquely in the direction of flow. Drains may be connected independently to the public sewer so that each building owner is responsible for the maintenance of the drainage system for that building. In situations where there would be long drain runs, it may be more economical to connect each drain to a private sewer. This requires only one sewer connection for several buildings. Maintenance of the private sewer is shared between the separate users.

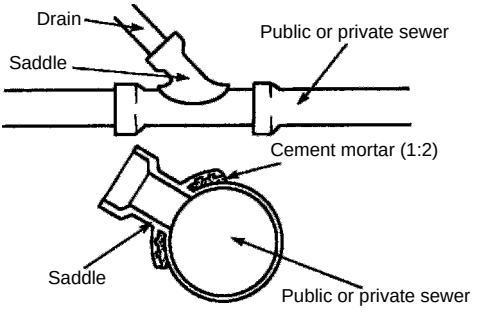


Use of separate drains



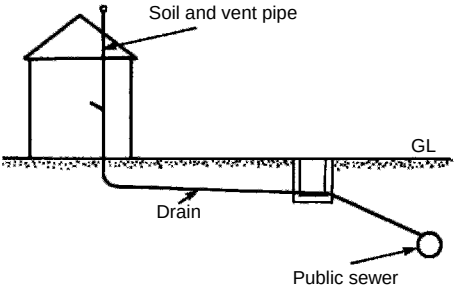
Use of private sewer

Connection of a drain or private sewer to the public sewer can be made with a manhole. If one of these is used at every connection, the road surface is unnecessarily disrupted. Therefore a saddle is preferred, but manhole access is still required at no more than 90 m intervals. Saddles are bedded in cement mortar in a hole made in the top of the sewer.

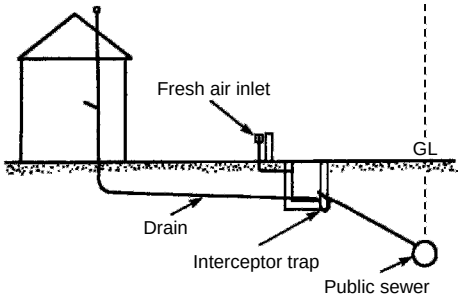


Use of saddle connection

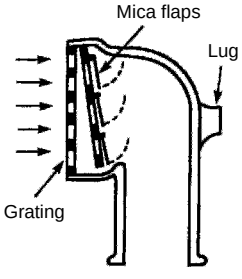
Venting of foul water drains is necessary to prevent a concentration of gases and to retain the air inside the drain at atmospheric pressure. This is essential to prevent the loss of trap water seals by siphonage or compression. The current practice of direct connection of the discharge stack and drain to the public sewer provides a simple means of ventilation through every stack. In older systems, generally pre-1950s, an interceptor trap with a 65 mm water seal separates the drain from the sewer. The sewer is independently vented by infrequently spaced high level vent stacks. Through ventilation of the drain is by fresh air inlet at the lowest means of access and the discharge stack. It may still be necessary to use this system where new buildings are constructed where it exists. It is also a useful means of controlling rodent penetration from the sewer.



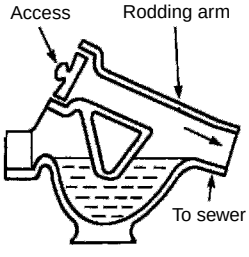
Without the use of an interceptor trap



With the use of an interceptor trap

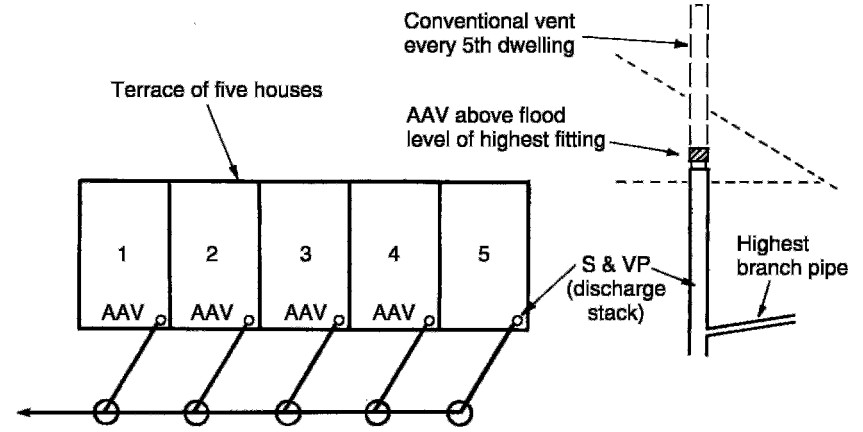


Fresh air inlet

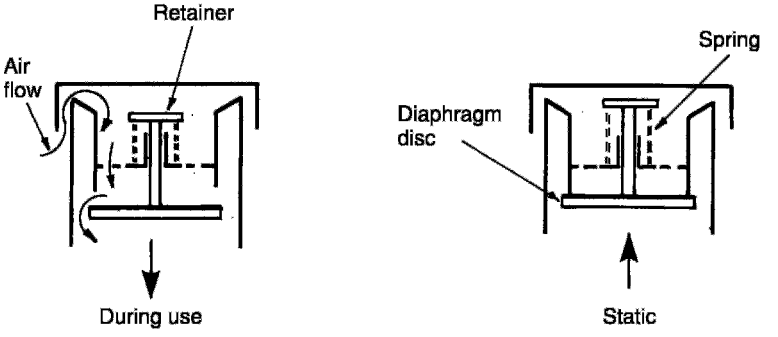


Interceptor trap

To reduce installation costs and to eliminate roof penetration of ventilating stacks, discharge stacks can terminate inside a building. This is normally within the roof space, i.e. above the highest water level of an appliance connected to the stack, provided the top of the stack is fitted with an air admittance valve (AAV). An AAV prevents the emission of foul air, but admits air into the stack under conditions of reduced atmospheric pressure. AAVs are limited in use to dwellings of no more than three storeys, in up to four adjacent buildings. The fifth building must have a conventional vent stack to ventilate the sewer.



Application

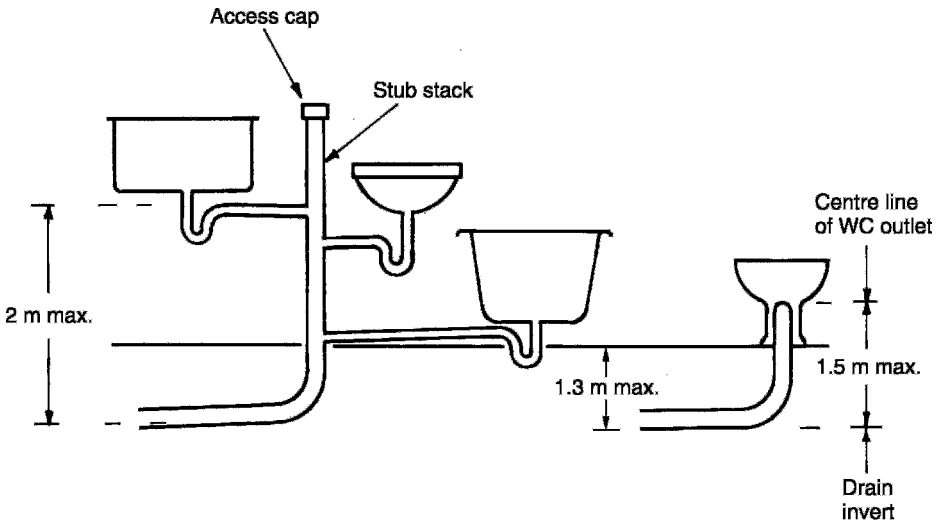


Function

Direct connection – a WC may discharge directly into a drain, without connection to a soil and ventilating stack. Application is limited to a maximum distance between the centre line of the WC trap outlet and the drain invert of 1·5 m.

Stub stack – this is an extension of the above requirement and may apply to a group of sanitary fittings. In addition to the WC requirement, no branch pipes to other fittings may be higher than 2 m above a connection to a ventilated stack or the drain invert.

The maximum length of branch drain from a single appliance to a means of drain access is 6 m. For a group of appliances, it is 12 m.

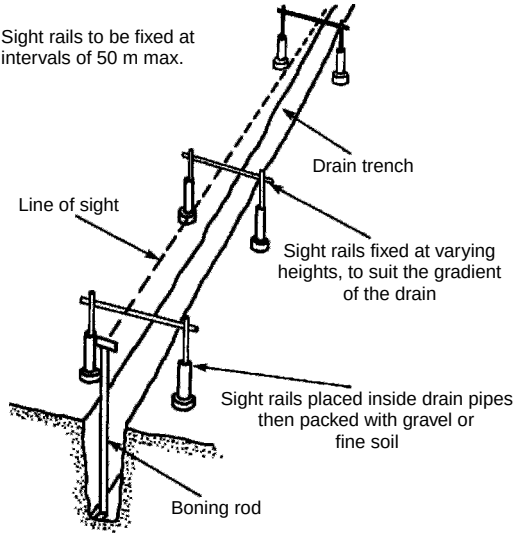


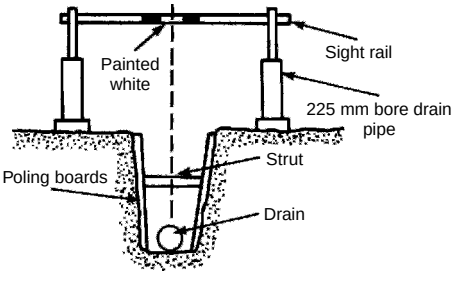
Stub stack for a group of fittings

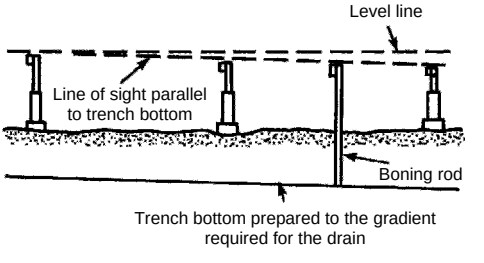
WC direct connection

Ref: Building Regulations, Approved Document H1, Section 1: Sanitary pipework.
BS EN 12056-2: Gravity drainage systems inside buildings. Sanitary pipework, layout and calculation.

The bottom of a drain trench must be excavated to a gradient. This is achieved by setting up sight rails, suitably marked to show the centre of the drain. These are located above the trench and aligned to the gradient required. At least three sight rails should be used. A boning rod (rather like a long `T' square) is sighted between the rails to establish the level and gradient of the trench bottom. Wooden pegs are driven into the trench bottom at about 1 m intervals. The required level is achieved by placing the bottom of the boning rod on each peg and checking top alignment with the sight rails. Pegs are adjusted accordingly and removed before laying the drains. For safe working in a trench, it is essential to provide temporary support to the excavation.





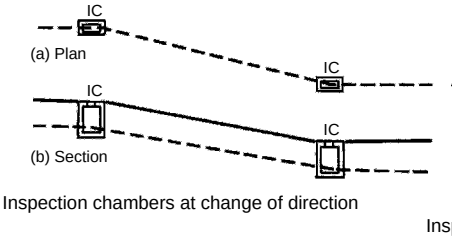


Drain access may be obtained through rodding points (page 224), shallow access chambers, inspection chambers and manholes. Pipe runs should be straight and access provided only where needed, i.e.:

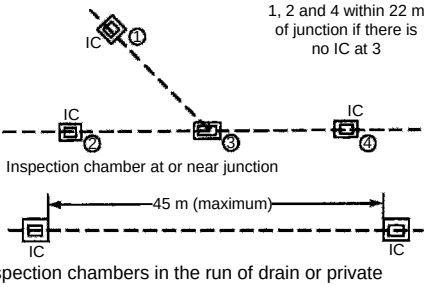
- at significant changes in direction
- at significant changes in gradient
- near to, or at the head of a drain
- where the drain changes in size
- at junctions
- on long straight runs.

Maximum spacing (m) of access points based on Table 10 of Approved Document H1 to the Building Regulations:

To / From	Access fitting		Junction	Inspection Chamber	Manhole
	Small	Large			
Start of drain	12	12	–	22	45
Rodding eye	22	22	22	45	45
Access fitting:					
150 diam	–	–	12	22	22
150 × 100	–	–	12	22	22
225 × 100	–	–	22	45	45
Inspection chamber	22	45	22	45	45
Manhole	–	–	–	45	90

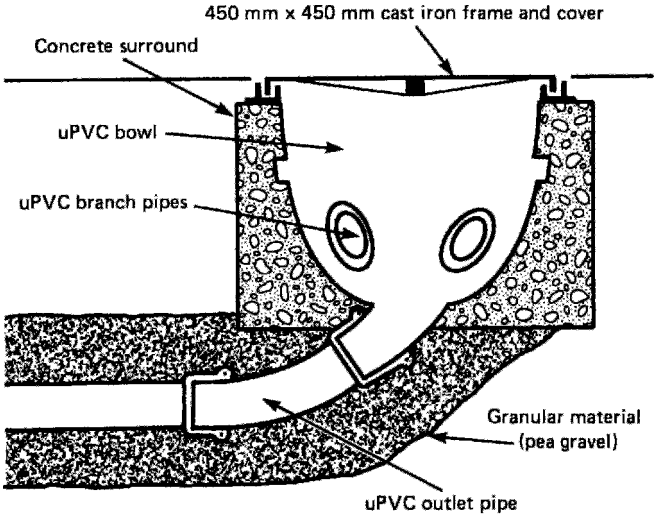


Inspection chambers at change of direction



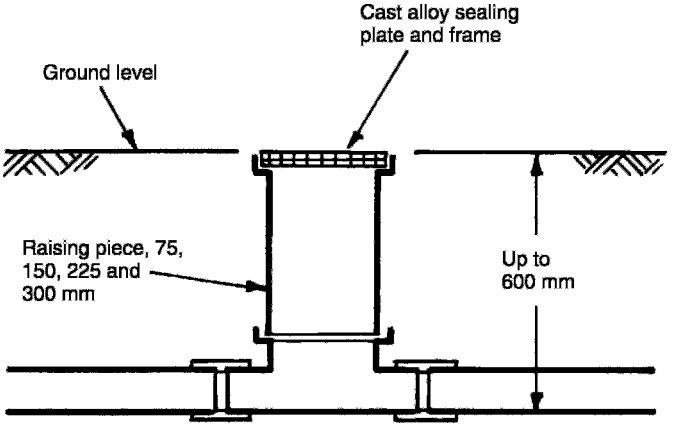
Inspection chambers in the run of drain or private sewer

Shallow access chambers or access fittings are small compartments similar in size and concept to rodding points, but providing drain access in both directions and possibly into a branch. They are an inexpensive application for accessing shallow depths up to 600 mm to invert. Within this classification manufacturers have created a variety of fittings to suit their drain products. The uPVC bowl variation shown combines the facility of an inspection chamber and a rodding point.



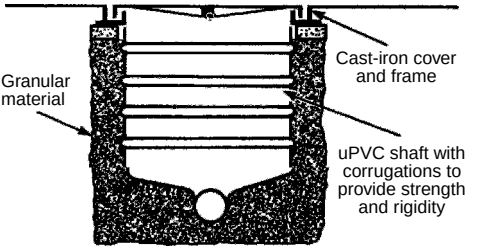
The Marscar access bowl

Note: Small lightweight cover plates should be secured with screws, to prevent unauthorised access, e.g. children.

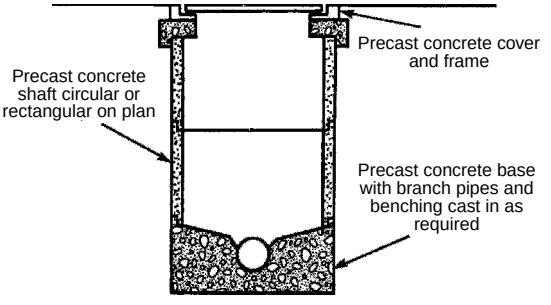


Clayware drain access fitting

Inspection chambers are larger than access chambers, having an open channel and space for several branches. They may be circular or rectangular on plan and preformed from uPVC, precast in concrete sections or traditionally constructed with dense bricks from a concrete base. The purpose of an inspection chamber is to provide surface access only, therefore the depth to invert level does not exceed 1 m.



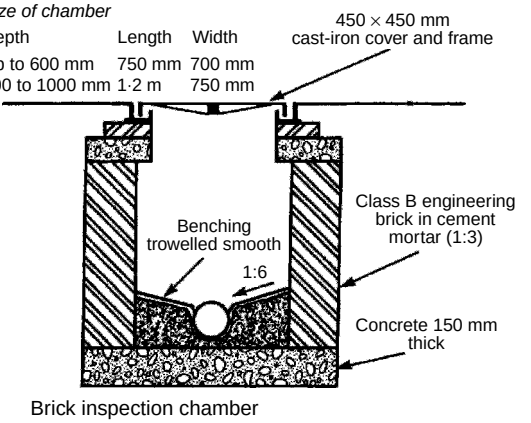
uPVC inspection chamber



Precast concrete inspection chamber

Size of chamber

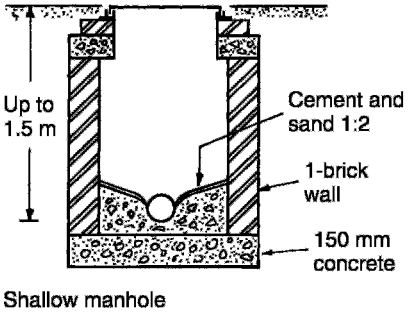
Depth	Length	Width
Up to 600 mm	750 mm	700 mm
600 to 1000 mm	1·2 m	750 mm



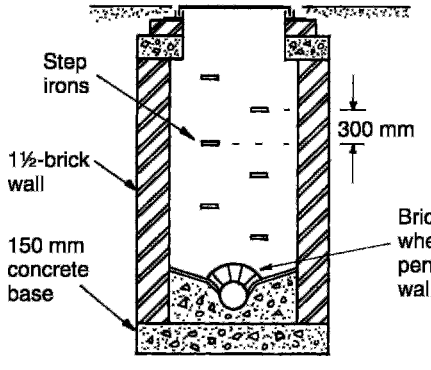
Brick inspection chamber

The term manhole is used generally to describe drain and sewer access. By comparison, manholes are large chambers with sufficient space for a person to gain access at drain level. Where the depth to invert exceeds 1 m, step irons should be provided at 300 mm vertical and horizontal spacing. A built-in ladder may be used for very deep chambers. Chambers in excess of 2·7 m may have a reduced area of access known as a shaft (min. 900 × 840 mm or 900 mm diameter), otherwise the following applies:

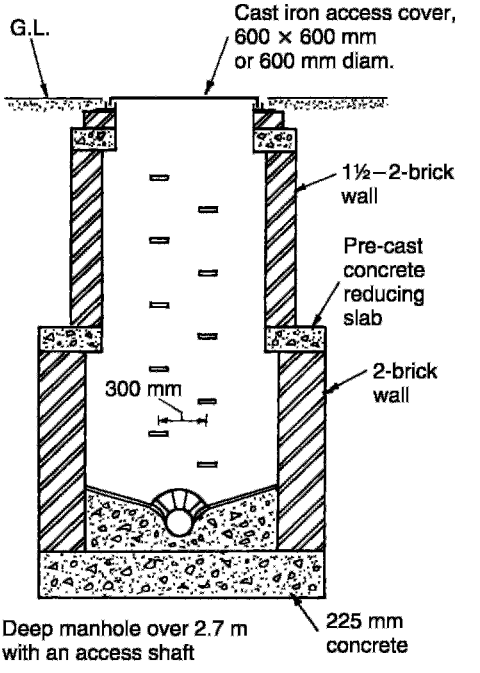
Depth (m)	Internal dimensions (mm) l × b	Cover size
<1·5	1200 × 750 or 1050 diam.	Min. dimension 600 mm
1·5–2.7	1200 × 750 or 1200 diam.	Min. dimension 600 mm
>2·7	1200 × 840 or 1200 diam.	Min. dimension 600 mm



Shallow manhole



Deep manhole, 1.5 to 2.7 m

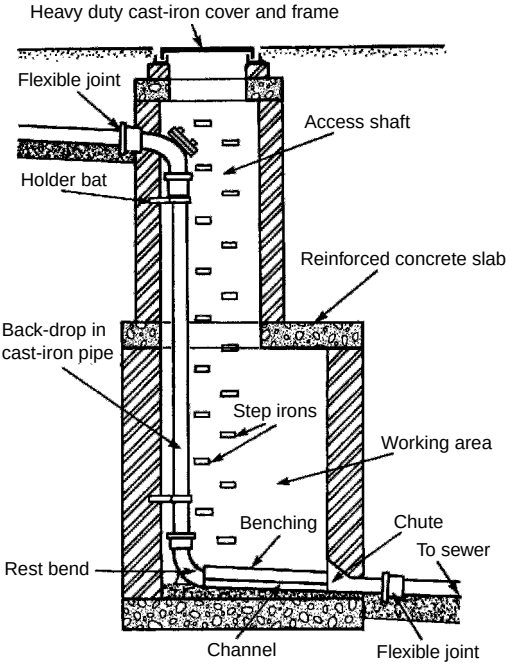


Deep manhole over 2.7 m with an access shaft

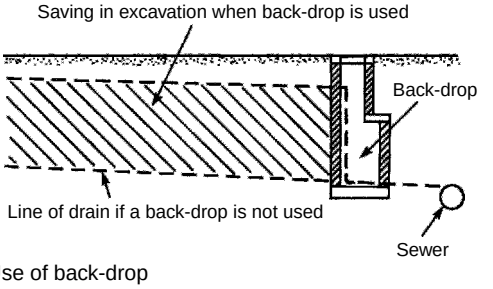
Back-drop Manhole

Where there is a significant difference in level between a drain and a private or public sewer, a back-drop may be used to reduce excavation costs. Back-drops have also been used on sloping sites to limit the drain gradient, as at one time it was thought necessary to regulate the velocity of flow. This is now considered unnecessary and the drain may be laid to the same slope as the ground surface. For use with cast-iron and uPVC pipes up to 150 mm bore, the back-drop may be secured inside the manhole. For other situations, the back-drop is located outside the manhole and surrounded with concrete.

The access shaft should be 900 × 840 mm minimum and the working area in the shaft at least 1·2 m × 840 mm.



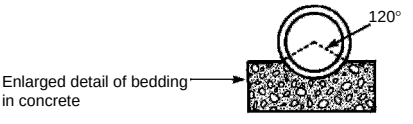
Detail of back-drop

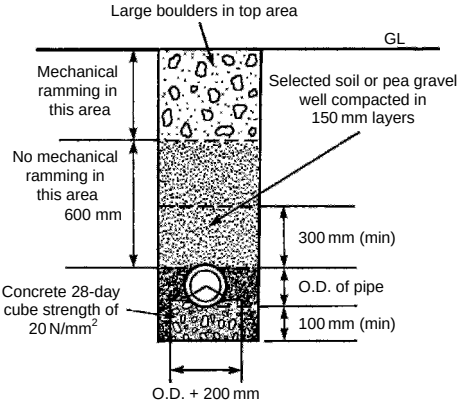


Use of back-drop

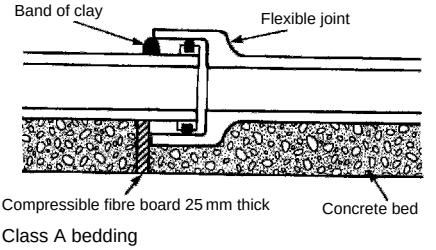
Drains must be laid with due regard for the sub-soil condition and the imposed loading. The term bedding factor is applied to laying rigid drain pipes. This describes the ratio of the pipe strength when bedded to the pipe test strength as given in the relevant British Standard.

Class A bedding gives a bedding factor of 2·6, which means that a rigid drain pipe layed in this manner could support up to 2·6 times the quoted BS strength. This is due to the cradling effect of concrete, with a facility for movement at every pipe joint. This method may be used where extra pipe strength is required or great accuracy in pipe gradient is necessary. Class B bedding is more practical, considerably less expensive and quicker to use. This has a more than adequate bedding factor of 1·9. If used with plastic pipes, it is essential to bed and completely surround the pipe with granular material to prevent the pipe from distortion.

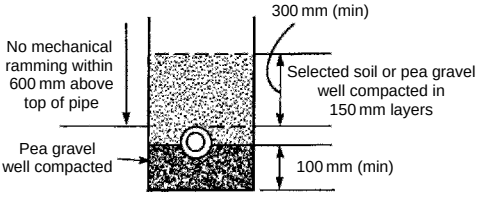




Class A bedding: bedding factor 2·6

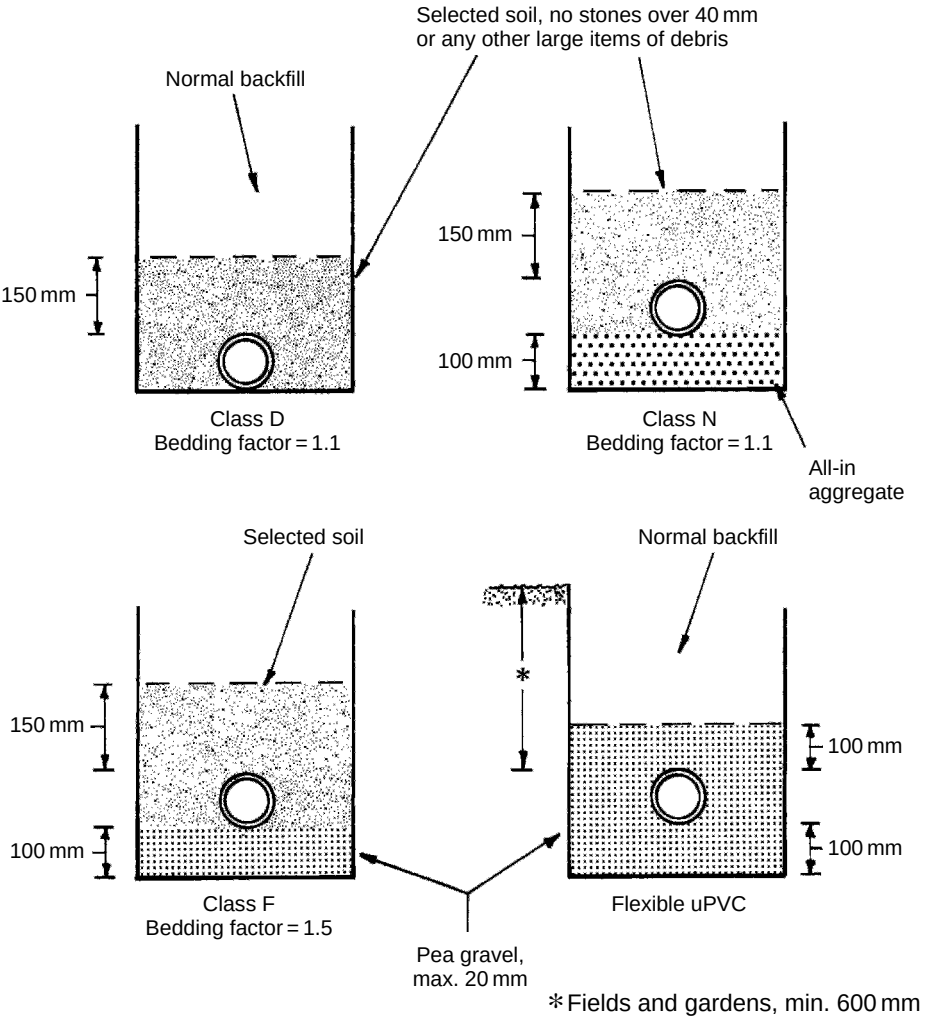


Class A bedding



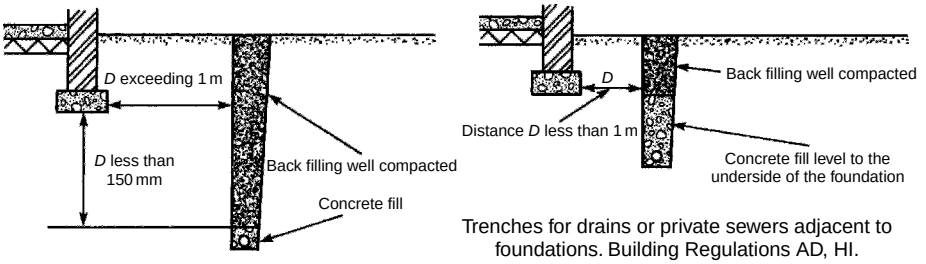
Class B bedding: bedding factor 1·9

Approved Document H to the Building Regulations provides many methods which will support, protect and allow limited angular and lineal movement to flexibly jointed clay drain pipes. Those shown below include three further classifications and corresponding bedding factors. Also shown is a suitable method of bedding flexible plastic pipes. In water-logged trenches it may be necessary to temporarily fill plastic pipes with water to prevent them floating upwards whilst laying. In all examples shown, space to the sides of pipes should be at least 150 mm.



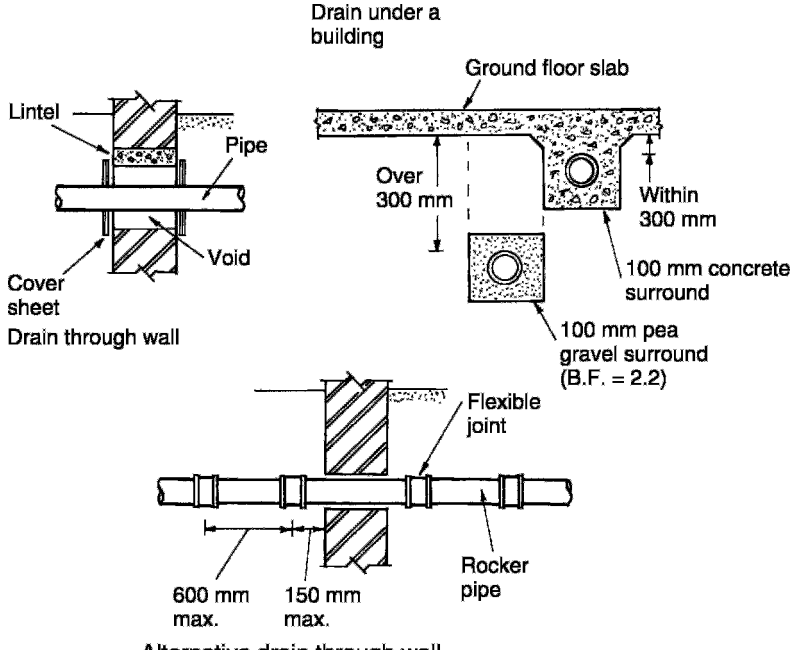
*Fields and gardens, min. 600 mm
Roads and drives, min. 900 mm (max. 6 m)

Drain trenches should be avoided near to and lower than building foundations. If it is unavoidable and the trench is within 1 m of the building, the trench is filled with concrete to the lowest level of the building. If the trench distance exceeds 1 m, concrete is filled to a point below the lowest level of the building equal to the trench distance less 150 mm.



Trenches for drains or private sewers adjacent to foundations. Building Regulations AD, HI.

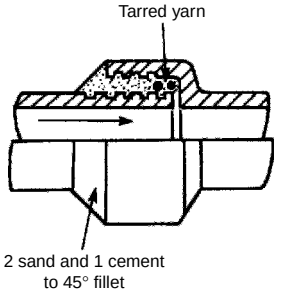
Drains under buildings should be avoided. Where it is impossible to do so, the pipe should be completely protected by concrete and integrated with the floor slab. If the pipe is more than 300 mm below the floor slab, it is provided with a granular surround. Pipes penetrating a wall below ground should be installed with regard for building settlement. Access through a void or with flexible pipe joints each side of the wall are both acceptable.



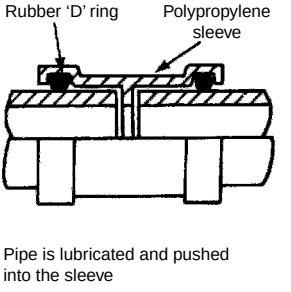
Rigid jointing of clay drain pipes is now rarely specified as flexible joints have significant advantages:

- They are quicker and simpler to make.
- The pipeline can be tested immediately.
- There is no delay in joint setting due to the weather.
- They absorb ground movement and vibration without fracturing the pipe.

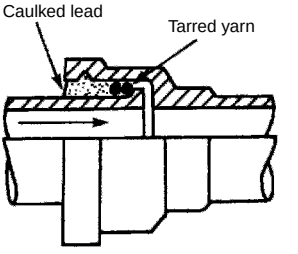
Existing clay drains will be found with cement and sand mortar joints between spigot and socket. Modern pipe manufacturers have produced their own variations on flexible jointing, most using plain ended pipes with a polypropylene sleeve coupling containing a sealing ring. Cast iron pipes can have spigot and sockets cold caulked with lead wool. Alternatively, the pipe can be produced with plain ends and jointed by rubber sleeve and two bolted couplings. Spigot and socket uPVC pipes may be jointed by solvent cement or with a push-fit rubber 'O' ring seal. They may also have plain ends jointed with a uPVC sleeve coupling containing a sealing ring.



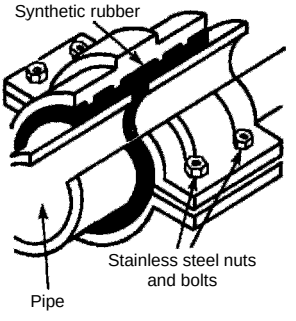
Cement mortar joint on clay pipe



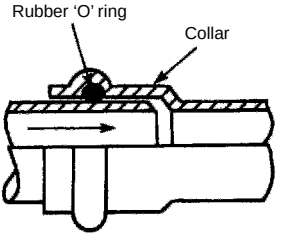
Flexible joint on clay pipe



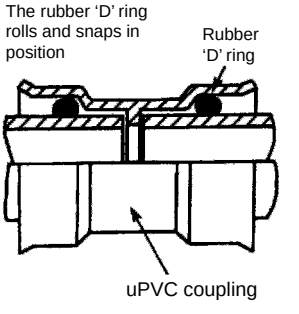
Caulked lead joint on cast-iron pipe



Flexible joint on cast-iron pipe



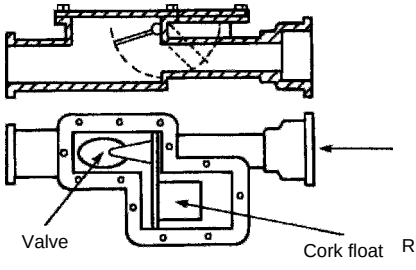
Flexible joint on uPVC pipe



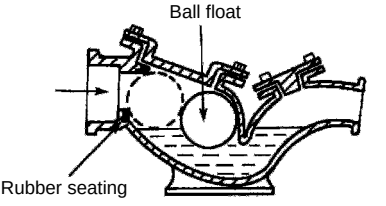
Flexible joint on uPVC pipe

Where there is a possibility of a sewer surcharging and back flooding a drain, an anti-flooding facility must be fitted. For conventional drainage systems without an interceptor trap, an anti-flooding trunk valve may be fitted within the access chamber nearest the sewer. If an interceptor trap is required, an anti-flooding type can be used in place of a conventional interceptor. An anti-flooding gully may be used in place of a conventional fitting, where back flooding may occur in a drain.

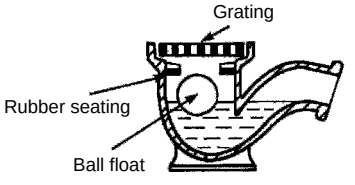
Waste water from canteen sinks or dishwashers contains a considerable amount of grease. If not removed it could build up and block the drain. Using a grease trap allows the grease to be cooled by a large volume of water. The grease solidifies and floats to the surface. At regular intervals a tray may be lifted out of the trap and cleaned to remove the grease.



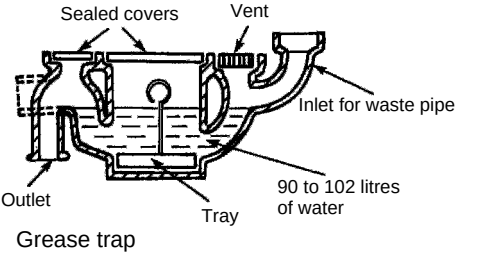
Anti-flooding trunk valve



Anti-flooding interceptor trap

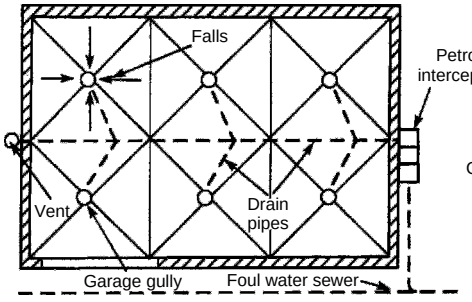


Anti-flooding gully trap

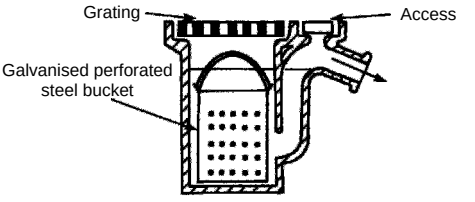


Grease trap

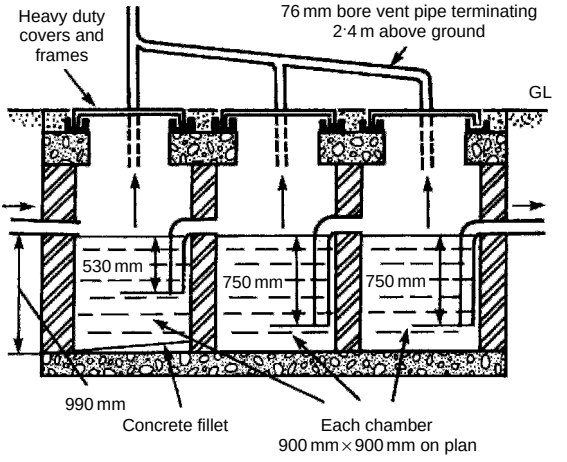
The Public Health Act prohibits discharge of petroleum and oil into a sewer. Garage floor washings will contain petrochemicals and these must be prevented from entering a sewer. The floor layout should be arranged so that one garage gully serves up to 50 m^2 of floor area. The gully will retain some oil and other debris, which can be removed by emptying the inner bucket. A petrol interceptor will remove both petrol and oil. Both rise to the surface with some evaporation through the vent pipes. The remaining oil is removed when the tanks are emptied and cleaned. The first chamber will also intercept debris and this compartment will require more regular cleaning. Contemporary petrol interceptors are manufactured from reinforced plastics for simple installation in a prepared excavation.



Plan of garage showing drainage

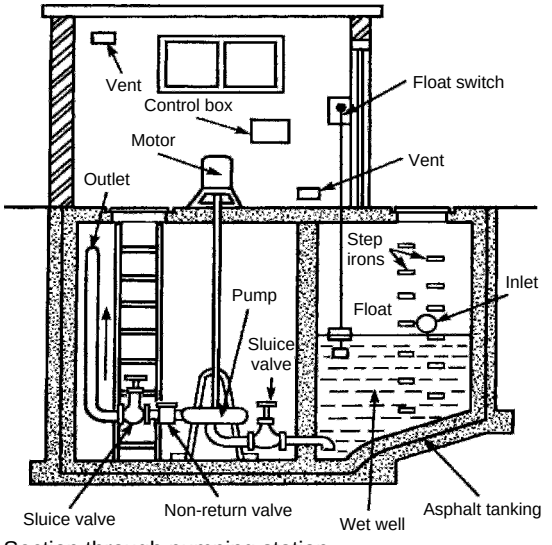


Section of garage gully

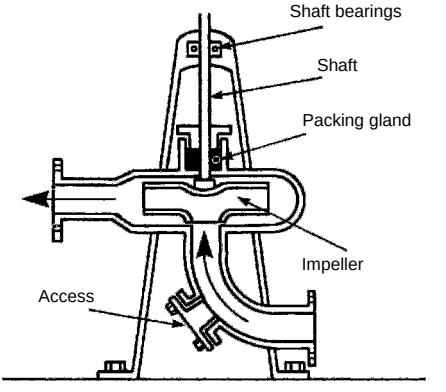


Longitudinal section of a petrol interceptor

The contents of drainage pipe lines should gravitate to the sewer and sewage processing plant. In some situations site levels or basement sanitary facilities will be lower than adjacent sewers and it becomes necessary to pump the drainage flows. A pumping station or plant room can be arranged with a motor room above or below surface level. Fluid movement is by centrifugal pump, usually immersed and therefore fully primed. For large schemes, two pumps should be installed with one on standby in the event of the duty pump failing. The pump impeller is curved on plan to complement movement of sewage and to reduce the possibility of blockage. The high level discharge should pass through a manhole before connecting to the sewer.



Section through pumping station



Section through centrifugal pump

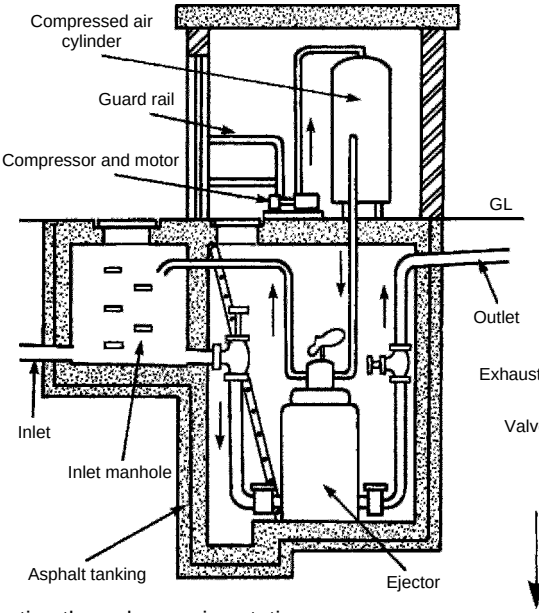
Refs: BS EN 12056-4: Gravity drainage systems inside buildings. Waste water lifting plants. Layout and calculation.
BS EN 12050: Waste water lifting plants for buildings and sites.

A sewage ejector may be used as an alternative to a centrifugal pump for lifting foul water. The advantages of an ejector are:

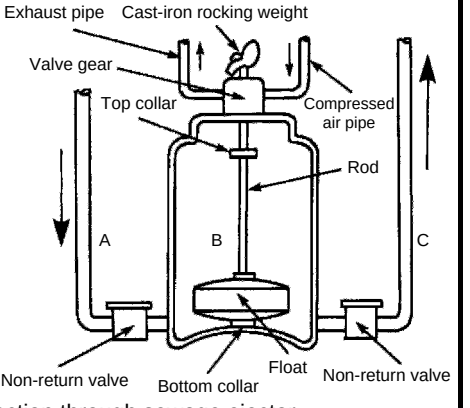
- Less risk of blockage.
- Fewer moving parts and less maintenance.
- A wet well is not required.
- One compressor unit can supply air to several ejectors.

Operation:

- Incoming sewage flows through inlet pipe A into ejector body B.
- Float rises to the top collar.
- Rod is forced upwards opening an air inlet valve and closing an exhaust valve.
- Compressed air enters the ejector body forcing sewage out through pipe C.
- The float falls to the bottom collar and its weight plus the rocking weight closes the air inlet valve and opens the exhaust valve.



Section through pumping station



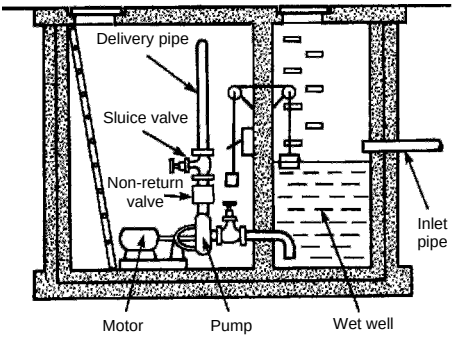
Section through sewage ejector

When considering methods of drainage pumping, equipment manufacturers should be consulted with the following details:

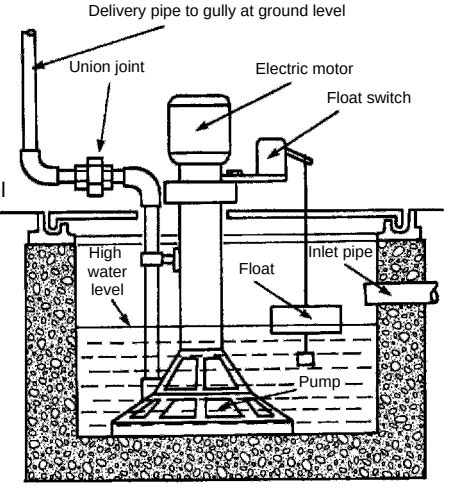
- Drainage medium – foul or surface water, or both.
- Maximum quantity – anticipated flow in m^3/h.
- Height to which the sewage has to be elevated.
- Length of delivery pipe.
- Availability of electricity – mains or generated.
- Planning constraints, regarding appearance and siting of pump station.

In the interests of visual impact, it is preferable to construct the motor room below ground. This will also absorb some of the operating noise.

In basements there may be some infiltration of ground water. This can be drained to a sump and pumped out as the level rises. In plant rooms a sump pump may be installed to collect and remove water from any leakage that may occur. It is also useful for water extraction when draining down boilers for servicing.



Pumping station with motor room below ground level

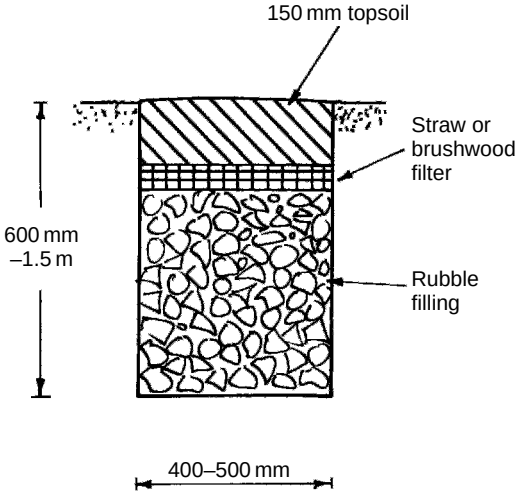


Sump pump

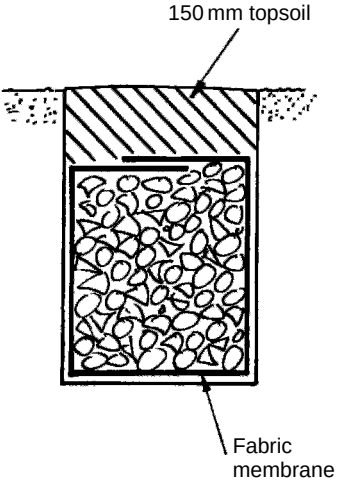
Design guidance for external pumped installations may be found in BS EN 752-6: Drain and sewer systems outside buildings. Pumping installations.

Ideally, buildings should be constructed with foundations above the subsoil water table. Where this is unavoidable or it is considered necessary to generally control the ground water, a subsoil drainage system is installed to permanently lower the natural water table. Various ground drainage systems are available, the type selected will depend on site conditions. The simplest is a French drain. It comprises a series of strategically located rubble-filled trenches excavated to a fall and to a depth below high water table. This is best undertaken after the summer, when the water table is at its lowest. Flow can be directed to a ditch, stream or other convenient outfall. In time the rubble will become silted up and need replacing.

An improvement uses a polyethylene/polypropylene filament fabric membrane to line the trench. This is permeable in one direction only and will also function as a silt filter. This type of drain is often used at the side of highways with an open rubble surface.

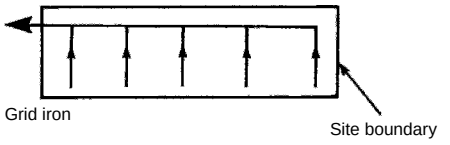


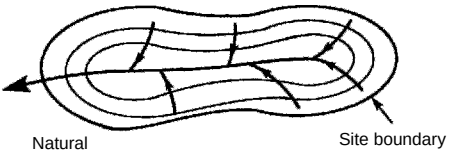
French drain

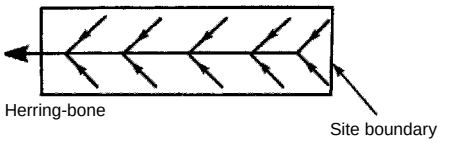


Lined rubble drain

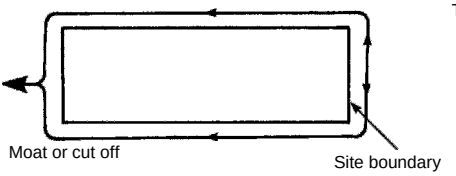
The layout and spacing of subsoil drainage systems depends on the composition and drainage qualities of the subsoil and the disposition of buildings. For construction sites the depth of drainage trench will be between 600 mm and 1·5 m. Shallower depths may be used in agricultural situations and for draining surface water from playing fields. Installation of pipes within the rubble drainage medium has the advantage of creating a permanent void to assist water flow. Suitable pipes are produced in a variety of materials including clay (open jointed, porous or perforated), concrete (porous (no-fine aggregate) or perforated) and uPVC (perforated). The pipe void can be accessed for cleaning and the system may incorporate silt traps at appropriate intervals. Piped outlets may connect to a surface water sewer with a reverse acting interceptor trap at the junction.

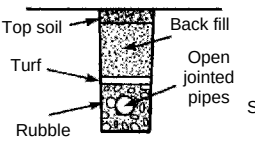




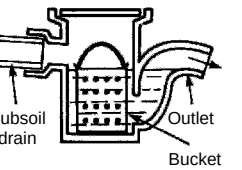








Method of pipe laying



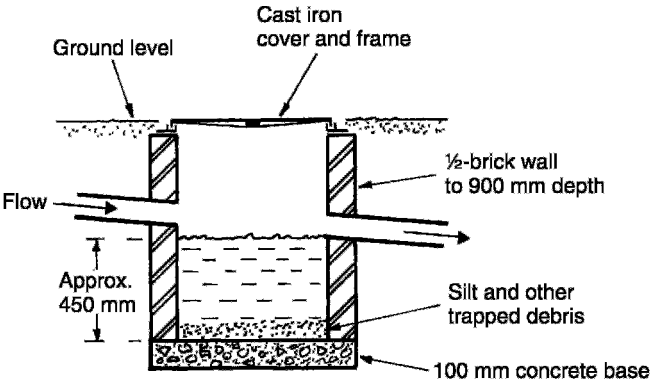
Detail of silt trap

Note: The installation of subsoil drainage may be necessary under the requirements of Building Regulation C3. The purpose of this is to prevent the passage of ground moisture into a building and the possibility of damage to a building.

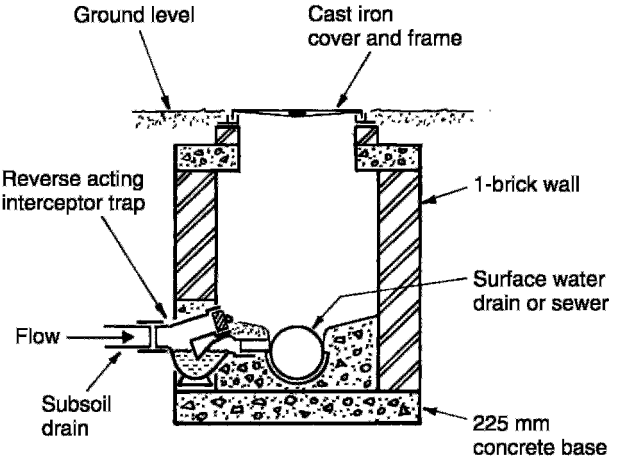
British Standard pipes commonly used for subsoil drainage:

- Perforated clay, BS EN 295-5.
- Porous clay, BS 1196.
- Profiled and slotted plastics, BS 4962.
- Perforated uPVC, BS 4660.
- Porous concrete, BS withdrawn no manufacturing interest.

Silt and other suspended particles will eventually block the drain unless purpose-made traps are strategically located for regular cleaning. The example shown on the previous page is adequate for short drain runs, but complete systems will require a pit which can be physically accessed. This is an essential requirement if the drain is to connect to a public surface water sewer. In order to protect flow conditions in the sewer, the local water authority may only permit connection via a reverse acting interceptor trap. This item does not have the capacity to function as a silt trap.



Silt trap or catch pit



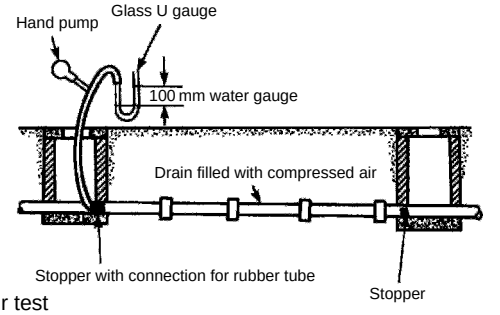
Subsoil drain outlet to a sewer

Drains must be tested before and after backfilling trenches.

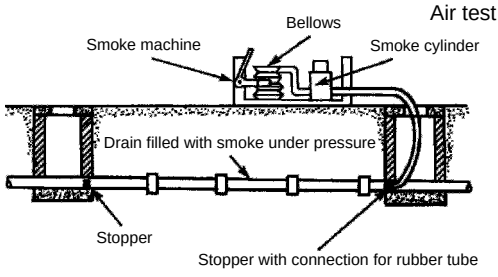
Air test – the drain is sealed between access chambers and pressure tested to 100 mm water gauge with hand bellows and a 'U' gauge (manometer). The pressure must not fall below 75 mm during the first 5 minutes.

Smoke test – may be used to detect leakage. The length of drain to be tested is sealed and smoke pumped into the pipes from the lower end. The pipes should then be inspected for any trace of smoke. Smoke pellets may be used in the smoke machine or with clay and concrete pipes they may be applied directly to the pipe line.

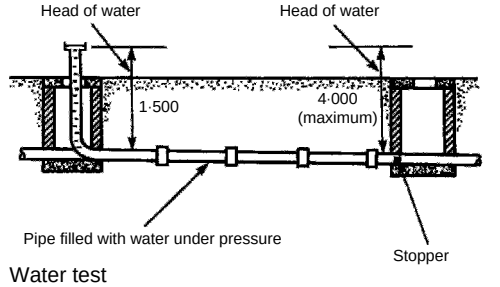
Water test – effected by stopping the lower part of the drain and filling the pipe run with water from the upper end. This requires a purpose-made test bend with an extension pipe to produce a 1·5 m head of water. This should stand for 2 hours and if necessary topped up to allow for limited porosity. For the next 30 minutes, maximum leakage for 100 mm and 150 mm pipes is 0·05 and 0·08 litres per metre run respectively.



Air test



Smoke test



Water test

Where a surface water sewer is not available, it may be possible to dispose of rainwater into a soakaway. A soakaway will only be effective in porous soils and above the water table. Water must not be allowed to flow under a building and soakaways should be positioned at least 3 m away (most local authorities require 5 m). A filled soakaway is inexpensive to construct, but it will have limited capacity. Unfilled or hollow soakaways can be built of precast concrete or masonry.

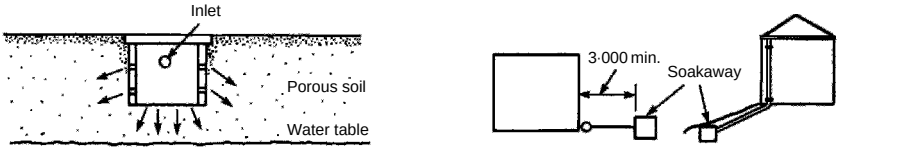
Soakaway capacity can be determined by applying a rainfall intensity of at least 50 mm per hour to the following formula:

$$C \times A \times R \div 3$$

where C = capacity in m^3
A = area to be drained in m^2
R = rainfall in metres per hour.

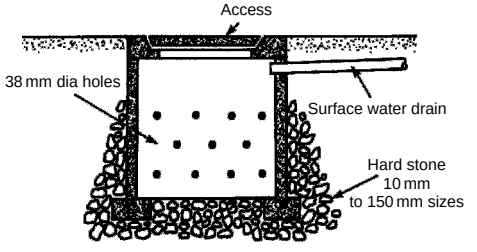
E.g. a drained area of 150 m^2

$C = 150 \times 0{\cdot}050 \div 3 = 2{\cdot}5\ m^3$

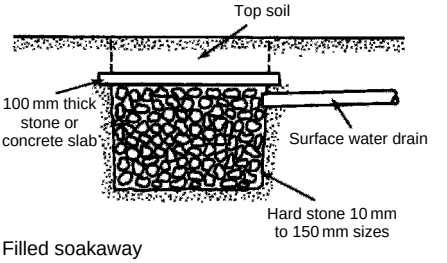


(a) Section (b) Plan (c) Best position for a soakaway

Siting of a soakaway



Precast concrete soakaway



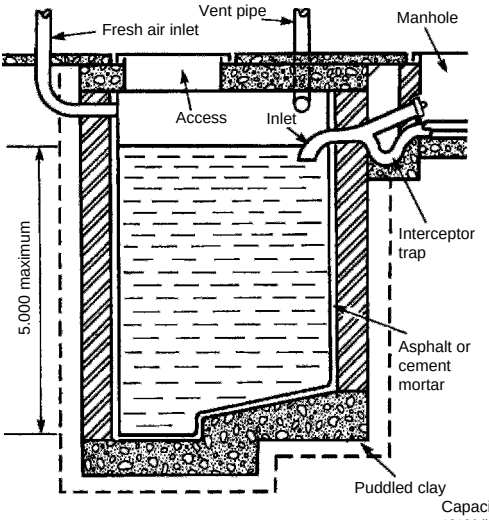
Filled soakaway

Note: BRE Digest 365: Soakaway Design, provides a more detailed approach to capacity calculation.

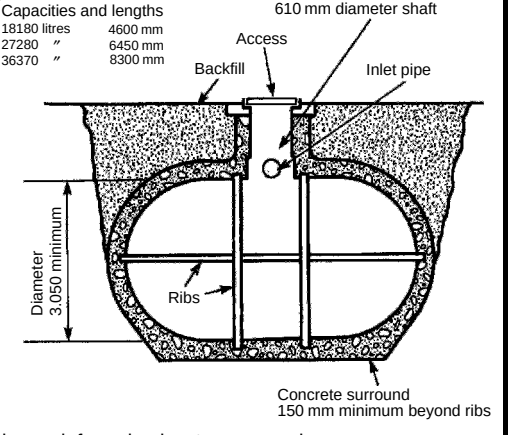
A cesspool is an acceptable method of foul water containment where main drainage is not available. It is an impervious chamber requiring periodic emptying, sited below ground level. Traditional cesspools were constructed of brickwork rendered inside with waterproof cement mortar. Precast concrete rings supported on a concrete base have also been used, but factory manufactured glass reinforced plastic units are now preferred. The Building Regulations require a minimum capacity below inlet level of 18 000 litres. A cesspool must be impervious to rainwater, well ventilated and have no outlets or overflows. It should be sited at least 15 m from a dwelling.

Capacity is based on 150 litres per person per day at 45 day emptying cycles, e.g. a four-person house:

$$= 4 \times 150 \times 45 + 27\,000 \text{ litres } (27 \text{ m}^3)$$



Brick cesspool



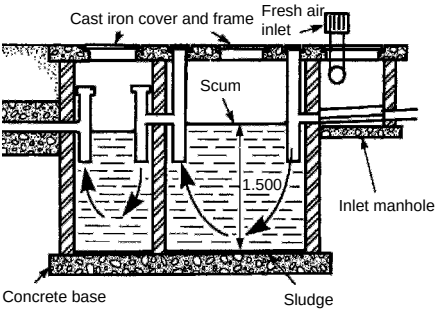
Glass reinforced polyester cesspool

Where main drainage is not available a septic tank is preferable to a cesspool. A septic tank is self-cleansing and will only require annual desludging. It is in effect a private sewage disposal plant, which is quite common for buildings in rural areas. The tank is a watertight chamber in which the sewage is liquefied by anaerobic bacterial activity. This type of bacteria lives in the absence of oxygen which is ensured by a sealed cover and the natural occurrence of a surface scum or crust. Traditionally built tanks are divided into two compartments with an overall length of three times the breadth. Final processing of sewage is achieved by conveying it through subsoil drainage pipes or a biological filter. Capacity is determined from the simple formula:

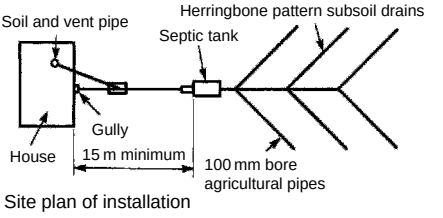
$$C = (180 \times P) + 2000$$

where: C = capacity in litres
P = no. of persons served

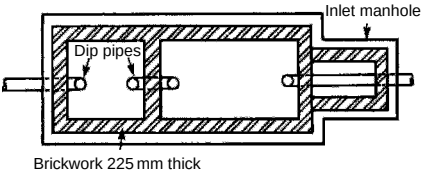
E.g. 10 persons; $C = (180 \times 10) + 2000 = 3800$ litres ($3{\cdot}8\ m^3$).



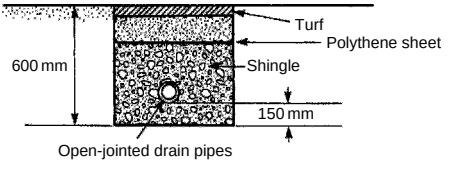
Longitudinal section of septic tank minimum volume under Building Regulations = $2.7\ m^3$



Site plan of installation

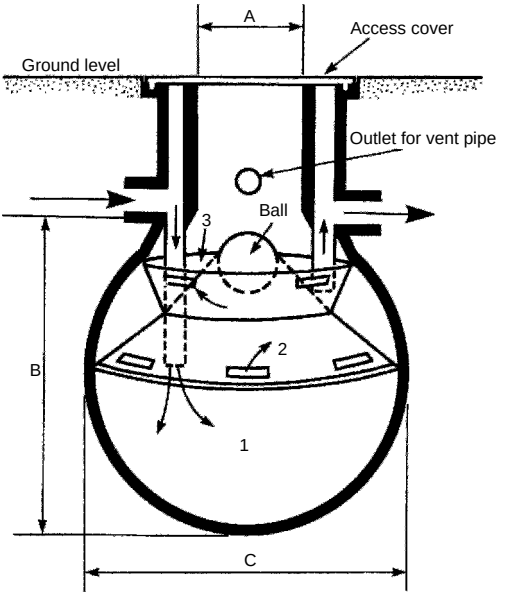


Plan of septic tank



Subsoil irrigation pipe trench

The Klargester settlement tank is a simple, reliable and cost-effective sewage disposal system manufactured from glass reinforced plastics for location in a site prepared excavation. The tanks are produced in capacities ranging from 2700 to 100 000 litres, to suit a variety of applications from individual houses to modest developments including factories and commercial premises. The sewage flows through three compartments (1,2,3) on illustration where it is liquefied by anaerobic bacterial activity. In similarity with traditionally built tanks, sludge settlement at the base of the unit must be removed annually. This is achieved by pushing away the floating ball to give extraction tube access into the lowest chamber. Processed sewage may be dispersed by subsoil irrigation or a biological filter.



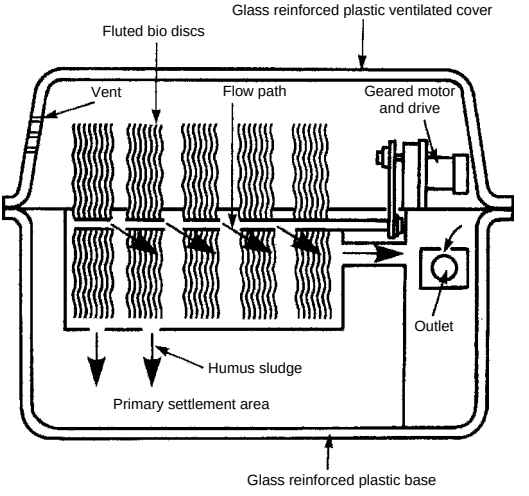
Section through tank

Capacity of tank in litres	Number of users with flow rate per head per day		Nominal dimensions in mm.		
	180 litres	250 litres	A	B	C
2700	4	3	610	1850	1800
3750	9	7	610	2060	2000
4500	14	10	610	2150	2100
6000	22	16	610	2400	2300
7500	30	22	610	2630	2500
10000	44	32	610	2800	2740

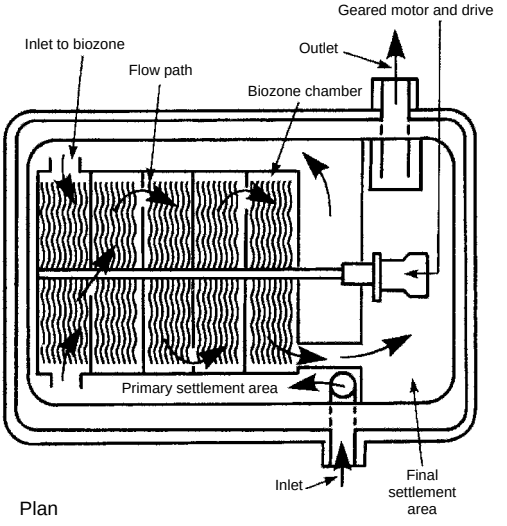
Ref: Building Regulations, Approved Document H2: Waste water treatment and cesspools.

Biodisc Sewage Treatment Plant

The biological disc has many successful applications to modest size buildings such as schools, prisons, country clubs, etc. It is capable of treating relatively large volumes of sewage by an accelerated process. Crude sewage enters the biozone chamber via a deflector box which slows down the flow. The heavier solids sink to the bottom of the compartment and disperse into the main sludge zone. Lighter solids remain suspended in the biozone chamber. Within this chamber, micro-organisms present in the sewage adhere to the partially immersed slowly rotating discs to form a biologically active film feeding on impurities and rendering them inoffensive. Baffles separate the series of rotating fluted discs to direct sewage through each disc in turn. The sludge from the primary settlement zone must be removed every 6 months.

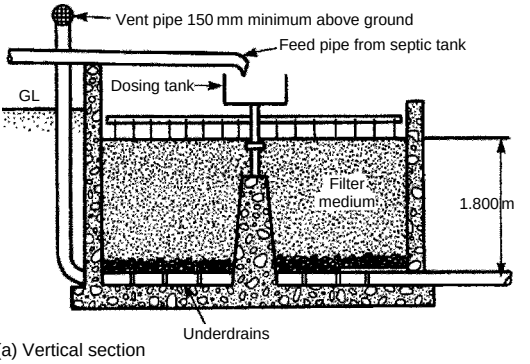


Longitudinal section

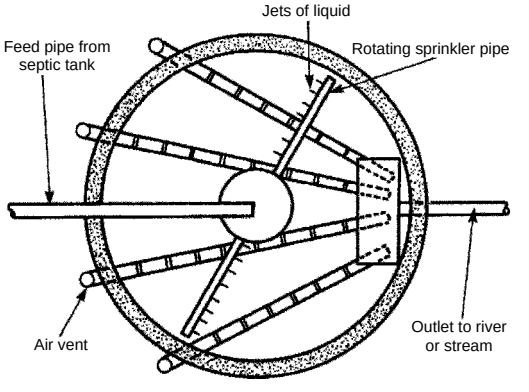


Plan

Treatment of septic tank effluent – liquid effluent from a septic tank is dispersed from a rotating sprinkler pipe over a filter of broken stone, clinker, coke or polythene shingle. The filter surfaces become coated with an organic film which assimilates and oxidises the pollutants by aerobic bacterial activity. This type of bacteria lives in the presence of oxygen, encouraged by ventilation through under-drains leading to a vertical vent pipe. An alternative process is conveyance and dispersal of septic tank effluent through a system of subsoil drains or a drainage field. To succeed, the subsoil must be porous and the pipes laid above the highest water table level. Alternatively, the primary treated effluent can be naturally processed in constructed wetland phragmite or reed beds (see page 256). Whatever method of sewage containment and processing is preferred, the local water authority will have to be consulted for approval.



(a) Vertical section



(b) Plan

Volume of filter
For up to 10 persons – 1 m^3/person
From 10–50 persons – 0.8 m^3/person
Over 50–300 persons – 0.6 m^3/person

Biological filter

Drainage fields and mounds are a less conspicuous alternative to use of a biological filter for secondary processing of sewage. Disposal and dispersal is through a system of perforated pipes laid in a suitable drainage medium.

Location:

- Min. 10 m from any watercourse or permeable drain.
- Min. 50 m from any underground water supply.
- Min. distance from a building:

<5 people	15 m
6–30 people	25 m
31–100 people,	40 m
>100 people	70 m

- Downslope of any water source.
- Unencroached by any other services.
- Unencroached by access roads or paved areas.

Ground quality:

- Preferably granular, with good percolation qualities. Subsoils of clay composition are unlikely to be suited.
- Natural water table should not rise to within 1 m of distribution pipes invert level.
- Ground percolation test:

  1. Dig several holes 300 × 300 mm, 300 mm below the expected distribution pipe location.
  2. Fill holes to a 300 mm depth of water and allow to seep away overnight.
  3. Next day refill holes to 300 mm depth and observe time in seconds for the water to fall from 225 mm depth to 75 mm. Divide time by 150 mm to ascertain average time (Vp) for water to drop 1 mm.
  4. Apply floor area formula for drainage field:

  $$At = p \times Vp \times 0{\cdot}25$$

  where, At = floor area (m^2)

  p = no. of persons served

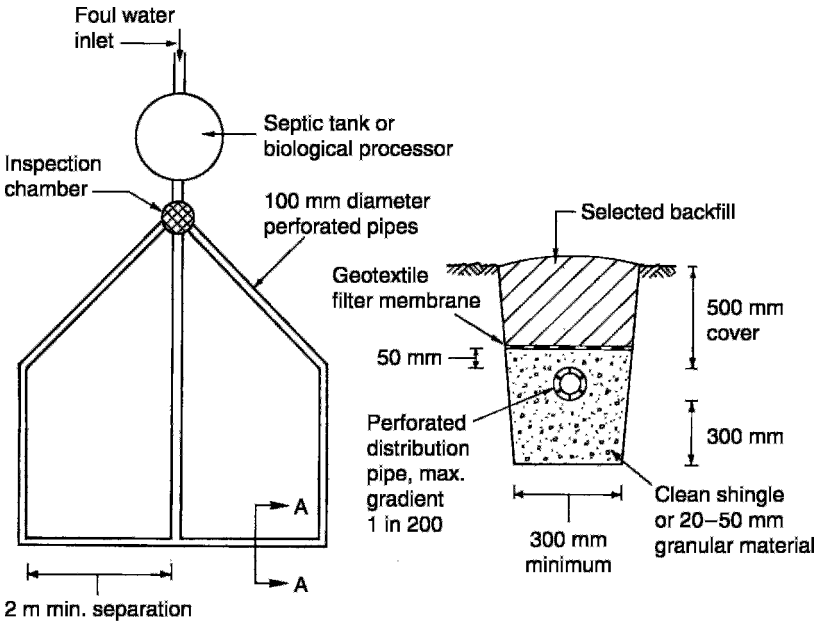
  e.g. 40 min (2400 secs) soil percolation test time in a system serving 6 persons.

  $$Vp = 2400 \div 150 = 16$$

  $$At = 6 \times 16 \times 0{\cdot}25 = 24\ m^2$$

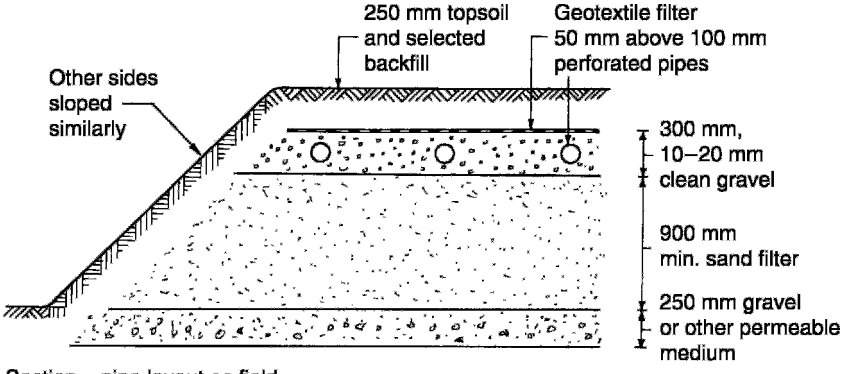
Note: Vp should be between 12 and 100. Less than 12 indicates that untreated effluent would percolate into the ground too rapidly. A figure greater than 100 suggests that the field may become saturated.

Typical drainage field



Typical drainage field

Typical constructed drainage mound

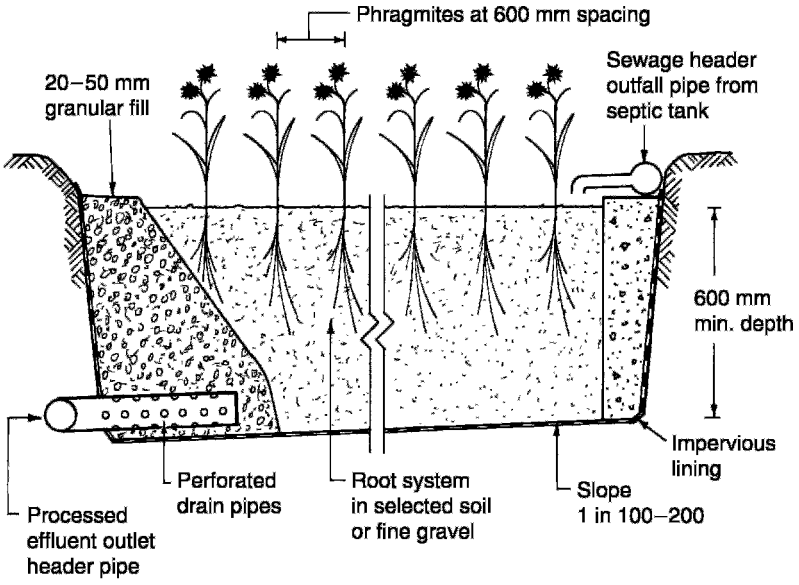


Section – pipe layout as field

Typical constructed drainage mound

These provide a natural method for secondary treatment of sewage from septic tanks or biological processing equipment.

Common reeds (Phragmites australis) are located in prepared beds of selected soil or fine gravel. A minimum bed area of 20 m^2 is considered adequate for up to four users. 5 m^2 should be added for each additional person. Reeds should be spaced about every 600 mm and planted between May and September. For practical purposes application is limited to about 30 people, due to the large area of land occupied. Regular maintenance is necessary to reduce unwanted weed growth which could restrict fluid percolation and natural processing. The site owners have a legal responsibility to ensure that the beds are not a source of pollution, a danger to health or a nuisance.



Section through a typical reed bed

Ref. Building Regulations, Approved Document H2: Waste treatment systems and cesspools.

Extreme weather situations in the UK have led to serious property damage from flooding, as drains, rivers and other watercourses are unable to cope with the unexpected volumes of surface water. A possible means of alleviating this and moderating the flow of surface water is construction of SUDS between the drainage system and its outfall.

Objectives are to:

- decrease the volume of water discharging or running-off from a site or building
- reduce the run-off rate
- filter and cleanse the debris from the water flow.

Formats:

- soakaways
- swales
- infiltration basins and permeable surfaces
- filter drains
- retention or detention ponds
- reed beds.

Soakaways – See page 248. For application to larger areas, see BS EN 752-4: Drain and sewer systems outside buildings.

Swales – Channels lined with grass. These slow the flow of water, allowing some to disperse into the ground as they convey water to an infiltration device or watercourse. They are best suited to housing, car parks and roads.

Infiltration basins and permeable surfaces – Purposely located depressions lined with grass and positioned to concentrate surface water into the ground. Permeable surfaces such as porous asphalt or paving can also be used to the same effect.

Filter drains – Otherwise known as French drains, see page 244. Note that drainage may be assisted by locating a perforated pipe in the centre of the gravel or rubble filling.

Retention or detention ponds – These are man-made catchments to contain water temporarily, for controlled release later.

Reed beds – These are not restricted to processing septic tank effluent, as shown on page 256. They are also a useful filter mechanism for surface water, breaking down pollutants and settlement of solids.

Ref: Sustainable Urban Drainage Systems – A design manual for England and Wales – CIRIA.

The size of gutters and downpipes will depend on the effective surface area to be drained. For flat roofs this is the plan area, whilst pitched roof effective area (A_e) can be calculated from:

Roof plan area ÷ Cosine pitch angle

Roofs over 70° pitch are treated as walls, with the effective area taken as:

Elevational area × 0·5.

Actual rainfall varies throughout the world. For UK purposes, a rate of 75 mm/h (R) is suitable for all but the most extreme conditions. Rainfall run-off (Q) can be calculated from:

$$Q = (Ae \times R) \div 3600 = l/s$$

E.g. a 45° pitched roof of 40 m^2 plan area.

$$Q = ([40 \div \text{Cos } 45°] \times 75) \div 3600$$
$$Q = ([40 \div 0{\cdot}707] \times 75) \div 3600$$
$$Q = 1{\cdot}18 \text{ l/s}$$

Size of gutter and downpipe will depend on profile selected, i.e. half round, ogee, box, etc. Manufacturers' catalogues should be consulted to determine a suitable size. For guidance only, the following is generally appropriate for half round eaves gutters with one end outlet:

Half round gutter (mm)	Outlet dia. (mm)	Flow capacity (l/s)
75	50	0·38
100	65	0·78
115	65	1·11
125	75	1·37
150	90	2·16

Therefore the example of a roof with a flow rate of 1·18 l/s would be adequately served by a 125 mm gutter and 75 mm downpipe.

- Where an outlet is not at the end, the gutter should be sized to the larger area draining into it.
- The distance between a stopped end and an outlet should not exceed 50 times the flow depth.
- The distance between two or more outlets should not exceed 100 times the flow depth (see example below).
- For design purposes, gutter slope is taken as less than 1 in 350.

E.g. a 100 mm half round gutter has a 50 mm depth of flow, therefore:

100 × 50 = 5000 mm or 5 m spacing of downpipes.

Ref: Building Regulations, Approved Document H3: Rainwater Drainage.

Another method of rainwater downpipe sizing is provided in BS EN 12056-3: Gravity drainage systems inside buildings. Roof drainage, layout and calculations. This Standard provides tabulated data calculated from the Wyly-Eaton equation to determine the capacity of rainwater pipes:

$$Q = 2.5 \times 10^{-4} \times k^{-0.167} \times d^{2.667} \times f^{1.667}$$

Where: Q = capacity of the rainwater pipe (l/s)

k = pipe roughness factor (usually taken as 0.25 mm)

d = inside diameter of the rainwater downpipe (mm)

f = filling degree or proportion of the rainwater pipe cross section filled with water (dimensionless)

d (mm)	Q (l/s)	f	
65	1.5	0.20	
65	3.4	0.33	
75	2.2	0.20	(see calculation below)
75	5.0	0.33	
90	3.5	0.20	
90	8.1	0.33	
100	4.6	0.20	
100	10.7	0.33	

Example by calculation for a 75 mm diameter rainwater pipe with a filling degree of 0.2:

$$Q = 2.5 \times 10^{-4} \times 0.25^{-0.167} \times 75^{2.667} \times 0.20^{1.667}$$

$$Q = 2.5 \times 10^{-4} \times 1.26 \times 100181.69 \times 0.07$$

$$Q = 2.21, \text{ i.e. } 2.2 \text{ l/s}$$

To calculate rainwater pipe diameter the formula is rearranged:

$$d^{2.667} = \frac{Q}{2.5 \times 10^{-4} \times k^{-0.167} \times f^{1.667}}$$ Using k = 0.25 mm and f = 0.20

$$d^{2.667} = \frac{2.2}{2.5 \times 10^{-4} \times 0.25^{-0.167} \times 0.20^{1.667}} = 74.89, \text{ i.e. } 75 \text{ mm}$$

This alternative procedure can be seen to allow a greater amount of flow capacity than that indicated on the previous page.

When designing rainfall run-off calculations for car parks, playgrounds, roads and other made up areas, a rainfall intensity of 50 mm/h is considered adequate. An allowance for surface permeability (P) should be included, to slightly modify the formula from the preceding page:

$$Q = (A \times R \times P)\ 3600 = l/s$$

Permeability factors:

Asphalt	0·85–0·95
Concrete	0·85–0·95
Concrete blocks (open joint)	0·40–0·50
Gravel drives	0·15–0·30
Grass	0·05–0·25
Paving (sealed joints)	0·75–0·85
Paving (open joints)	0·50–0·70

E.g. a paved area (P = 0·75) 50 m × 24 m (1200 m^2).

$$Q = (1200 \times 50 \times 0{\cdot}75) \div 3600$$
$$Q = 12.5 \text{ l/s or } 0{\cdot}0125 \text{ } m^3/s$$

The paved area will be served by several gullies (at 1 per 300 m^2 = 4) with subdrains flowing into a main surface water drain. Each drain can be sized according to the area served, but for illustration purposes, only the main drain is considered here. The pipe sizing formula is:

$$Q = V \times A$$

where: Q = quantity of water (m^3/s)
V = velocity of flow (min. 0·75 m/s) – see next page
A = area of water flowing (m^2)

Drains should not be designed to flow full bore as this leaves no spare capacity for future additions. Also, fluid flow is eased by the presence of air space. Assuming half full bore, using the above figure of 0.0125 m^3/s, and the minimum velocity of flow of 0·75 m/s:

$$Q = V \times A$$
$$0{\cdot}0125 = 0{\cdot}75 \times A$$

Transposing,

$$A = 0{\cdot}0125 \div 0{\cdot}75$$
$$A = 0{\cdot}017 \text{ } m^2$$

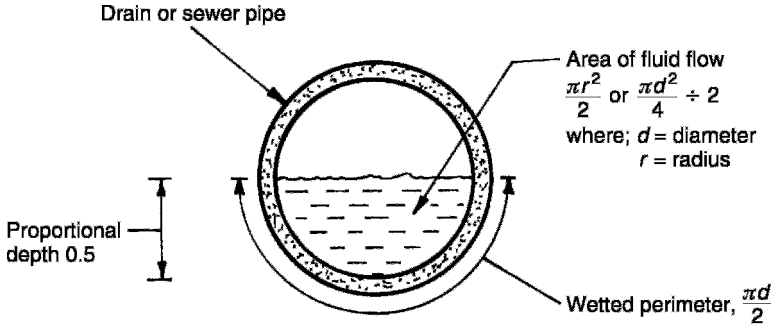
This represents the area of half the pipe bore, so the total pipe area is double, i.e. 0.034 m^2.
Area of a circle (pipe) = πr^2 where r = radius of pipe (m).
Transposing,

$$r = \sqrt{\text{Area} \div \pi}$$
$$r = \sqrt{0{\cdot}034 \div \pi}$$
$$r = 0{\cdot}104 \text{ m or } 104 \text{ mm}$$

Therefore the pipe diameter = 2 × 104 = 208 mm.
The nearest commercial size is 225 mm nominal inside diameter.

Velocity of flow – 0·75 m/s – is the accepted minimum to achieve self-cleansing. It is recognised that an upper limit is required to prevent separation of liquids from solids. A reasonable limit is 1·8 m/s for both surface and foul water drainage, although figures up to 3 m/s can be used especially if grit is present. The selected flow rate will have a direct effect on drain gradient, therefore to moderate excavation costs a figure nearer the lower limit is preferred. Also, if there is a natural land slope and excavation is a constant depth, this will determine the gradient and velocity of flow.

Hydraulic mean depth (HMD) – otherwise known as hydraulic radius represents the proportion or depth of flow in a drain. It will have an effect on velocity and can be calculated by dividing the area of water flowing in a drain by the contact or wetted perimeter. Thus for half full bore:



$$HMD = \frac{\pi r^2}{2} \div \frac{\pi d}{2}$$

This table summarises HMD for proportional flows:

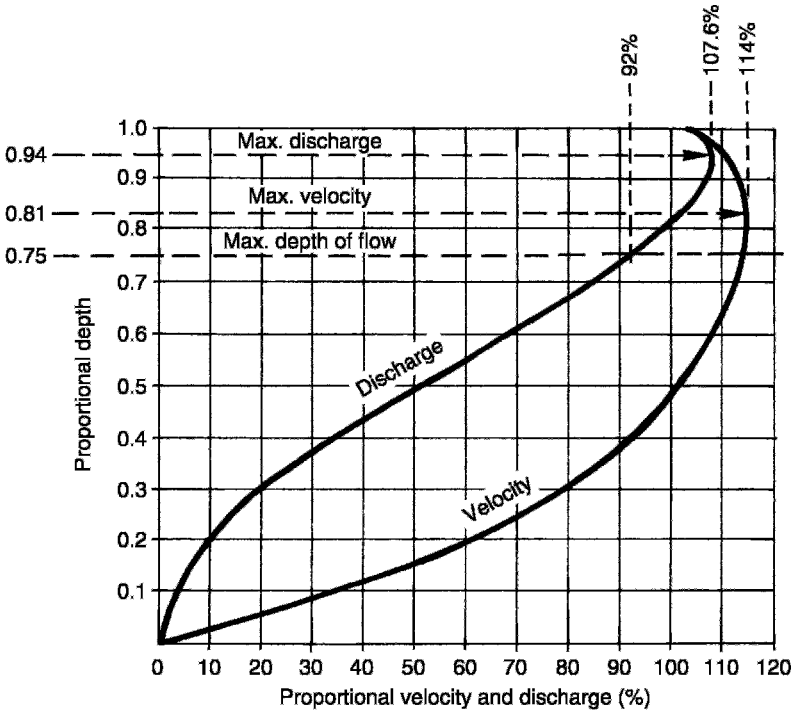
Depth of flow	HMD
0·25	Pipe dia. (m) ÷ 6·67
0·33	Pipe dia. (m) ÷ 5·26
0·50	Pipe dia. (m) ÷ 4·00
0·66	Pipe dia. (m) ÷ 3·45
0·75	Pipe dia. (m) ÷ 3·33
Full	Pipe dia. (m) ÷ 4·00

E.g. a 225 mm (0·225 m) drain flowing half bore:

HMD = 0·225 ÷ 4 = 0·05625

Drains are usually designed with a maximum flow condition of three quarters full bore, i.e. depth of flow or proportional depth 0.75. It is essential to maintain some air space within a drain to prevent pressure variations. Half full bore is a more conservative design, allowing ample space for future connections and extensions to the system.

The relationship between drain capacity or proportional depth of flow, velocity of flow (m/s) and discharge (m^3/s) is represented in graphical format:



Velocity, discharge and proportional depth

Taking the example on page 266 the drain is designed to flow at half full bore with a flow velocity of 0.8 m/s and discharge of 0.052 m^3/s. If at some later date, additional buildings are connected to the drainage system to produce an anticipated flow of up to 0.75 proportional depth, the graph indicates revised relative velocity and discharge rates of 114% or 0.912 m/s and 92% or 0.048 m^3/s, respectively.

The fall, slope or inclination of a drain or sewer will relate to the velocity of flow and the pipe diameter. The minimum diameter for surface water and foul water drains is 75 mm and 100 mm respectively.

Maguire's rule of thumb is an established measure of adequate fall on drains and small sewers. Expressing the fall as 1 in x, where 1 is the vertical proportion to horizontal distance x, then:

$$x = \text{pipe diameter in mm} \div 2{\cdot}5$$

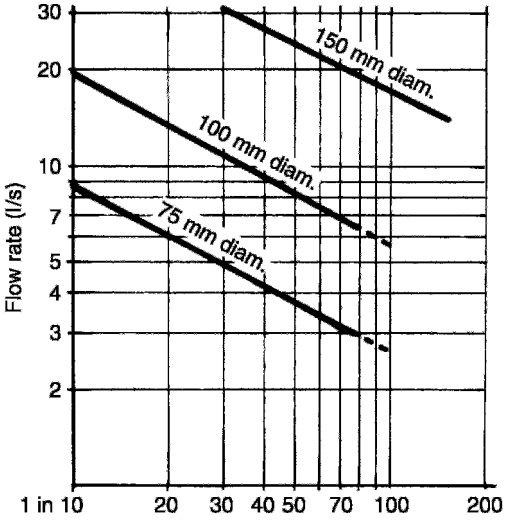
E.g. a 150 mm nominal bore drain pipe:

$$x = 150 \div 2{\cdot}5 = 60, \text{ i.e. 1 in 60 minimum gradient.}$$

Pipe dia. (mm)	Gradient
100	1 in 40
150	1 in 60
225	1 in 90
300	1 in 120

For full and half bore situations, these gradients produce a velocity of flow of about 1·4 m/s.

The Building Regulations, Approved Documents H1 and H3, provide guidance on discharge capacities for surface water drains running full and foul water drains running 0·75 proportional depth. The chart below is derived from this data:



Notes: (1) – – = Rainwater only.
(2) 75 mm is for rainwater or waste water (no soil) only.
(3) To convert l/s to m^3/s, divide by 1000.

An alternative approach to drainage design is attributed to the established fluid flow research of Antoine Chezy and Robert Manning. This can provide lower gradients:

Chezy's formula: $V = C\sqrt{m \times i}$

where, V = velocity of flow (min. 0·75 m/s)
C = Chezy coefficient
m = HMD (see page 261)
i = inclination or gradient as 1/X or $1 \div X$.

Manning's formula: $C = (1 \div n) \times (m)^{\frac{1}{6}}$

where:
C = Chezy coefficient
n = coefficient for pipe roughness 0·010*
m = HMD
$\frac{1}{6}$ = sixth root

*A figure of 0·010 is appropriate for modern high quality uPVC and clay drainware – for comparison purposes it could increase to 0·015 for a cast concrete surface.

E.g. A 300 mm (0·3 m) nominal bore drain pipe flowing 0·5 proportional depth half full bore). The Chezy coefficient can be calculated from Manning's formula:

$$\text{HMD} = 0{\cdot}3 \div 4 = 0{\cdot}075 \text{ (see page 261)}$$
$$C = (1 \div n) \times (m)^{\frac{1}{6}}$$
$$C = (1 \div 0.010) \times (0{\cdot}075)^{\frac{1}{6}} = 65$$

Using a velocity of flow shown on the previous page of 1·4 m/s, the minimum gradient can be calculated from Chezy's formula:

$$V = C\sqrt{m \times i}$$
$$1{\cdot}4 = 65\sqrt{0{\cdot}075 \times i}$$
$$(1{\cdot}4 \div 65)^2 = 0{\cdot}075 \times i$$
$$0{\cdot}00046 \div 0{\cdot}075 = i$$
$$i = 0{\cdot}00617$$
$$i = 1 \div X$$
$$\text{So, } X = 1 \div 0{\cdot}00617 = 162, \text{ i.e. 1 in 162}$$

Chezy formula – attributed to experiments that determined the relationship between fluid flow in open channels relative to the velocity of flow. In 1775 the Frenchman, Antoine Chezy published his formula which has since become the practical basis for drainage design calculations:

$$V = C\sqrt{m \times i}$$

Chezy's C cannot be evaluated as a pure number or as a constant. It has the dimensions of acceleration, i.e. $\sqrt{L \times (T^{-1})}$ where L is the length of drain run and T is time. Chezy's C is therefore a coefficient affected by the hydraulic mean depth (m) and the pipe surface roughness (n).

Kutter and Ganguillet formula – these Swiss engineers determined a factor for channel and pipe surface roughness (n) for a variety of materials ranging from glass (0·009) to rough timber (0.160). For purposes of modern pipe materials, these values or coefficients range from 0.010 to 0.015 as qualified on the previous page. On the basis of their research, in 1869 Kutter and Ganguillet produced a formula for evaluating Chezy's C:

$$C = \frac{23 + (0{\cdot}00155 \div s) + (1 \div n)}{1 + (23 + [0{\cdot}00155 \div s]) \times (n \div \sqrt{m})}$$

where, s is expressed as the sine of the bed slope or drain inclination

Manning formula – following the earlier work of Kutter and Ganguillet, in 1888 the Irish engineer Robert Manning produced his much simpler formula for the Chezy coefficient:

$$C = (1 \div n) \times (m)^{1/6}$$

The value of pipe surface roughness (n) being attributed to Kutter and Ganguillet. It is often referred to as Kutter's n.

Although extremely dated and quite empirical in their formulation, these formulae have stood the test of time. They are still favoured by engineers and drainage designers and continue to feature in research and product development.

Small drainage schemes:

<20 dwellings, 100 mm nom. bore pipe, min. gradient 1 in 80.

20–150 dwellings, 150 mm nom. bore pipe, min. gradient 1 in 150.

Minimum size for a public sewer is 150 mm. Most water authorities will require a pipe of at least 225 mm to allow for future developments and additions to the system.

For other situations, estimates of foul water flow may be based on water consumption of 225 litres per person per day. A suitable formula for average flow would be:

$$l/s = \frac{\text{Half consumption per person per day}}{6 \text{ hours} \times 3600 \text{ seconds}}$$

Note: 6 hours is assumed for half daily flow.

E.g. A sewer for an estate of 500, four-person dwellings:

$$l/s = \frac{112 \times 4 \times 500}{6 \times 3600} = 10{\cdot}4$$

Assuming maximum of 5 times average flow = 52 l/s or 0·052 m^3/s.

Using the formula $Q = V \times A$ (see 260) with a velocity of flow of, say, 0·8 m/s flowing half full bore (0·5 proportional depth):

$Q = 0{\cdot}052\ m^3/s$
$V = 0{\cdot}8\ m/s$
$A = \text{half bore}\ (m^2)$

Transposing the formula:

$A = Q \div V$
$A = 0{\cdot}052 \div 0{\cdot}8 = 0{\cdot}065\ m^2$

A represents half the bore, therefore the full bore area = 0·130 m^2.

Area of a circle (pipe) = πr^2, therefore $\pi r^2 = 0{\cdot}130$

Transposing: $r = \sqrt{0{\cdot}130 \div \pi}$

$r = 0{\cdot}203$ m radius

Therefore diameter = 0·406 m or 406 mm

Nearest commercial size is 450 mm nominal bore.

An alternative approach to estimating drain and sewer flows is by summation of discharge units and converting these to a suitable pipe size. Discharge units represent frequency of use and load producing properties of sanitary appliances. They are derived from data in BS EN 12056-2 and BS EN 752, standards for drainage systems inside and outside buildings, respectively. Although intended primarily for sizing discharge stacks, they are equally well applied to drains and sewers.

Appliance	Situation	No. of units
WC	Domestic	7
	Commercial	14
	Public	28
Basin	Domestic	1
	Commercial	3
	Public	6
Bath	Domestic	7
	Commercial	18
Sink	Domestic	6
	Commercial	14
	Public	27
Shower	Domestic	1
	Commercial	2
Urinal		0·3
Washing machine		4–7
Dishwasher		4–7
Waste disposal unit		7
Group of WC, bath and 1 or 2 basins		14
Other fittings with an outlet of:		
	50 mm nom. i.d.	7
	65 mm nom. i.d.	7
	75 mm nom. i.d.	10
	90 mm nom. i.d.	10
	100 mm nom. i.d.	14

Note:

Domestic = houses and flats.

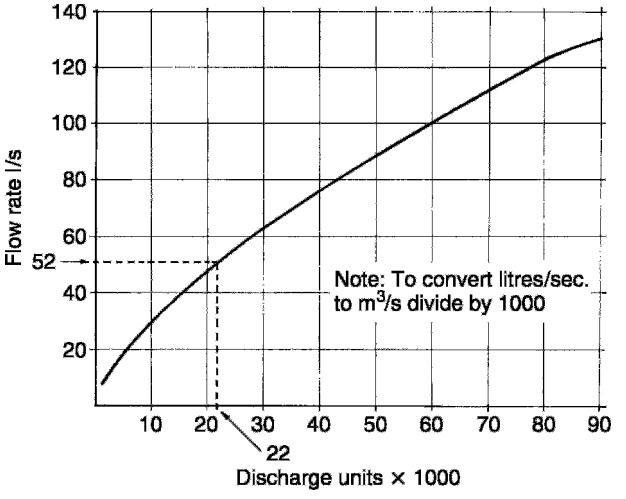
Commercial = offices, factories, hotels, schools, hospitals, etc.

Public or peak = cinemas, theatres, stadia, sports centres, etc.

Using the example from page 266, i.e. 500, four-person dwellings. Assuming 1 WC, 1 shower, 2 basins, 2 sinks, 1 group of appliances, washing machine and dishwasher per dwelling.

WC	7	discharge units
Shower	1	discharge unit
Basins	2	discharge units
Sinks	12	discharge units
Group	14	discharge units
Washing machine	4	discharge units
Dishwasher	4	discharge units

Total = 44 discharge units × 500 dwellings = 22000 discharge units.



Sewer size can be calculated for a 0·052 m^3/s flow at half full bore using the formula, Q = V × A as shown page 266. Gradient can be calculated using the Chezy and Manning formulas as shown on page 264.

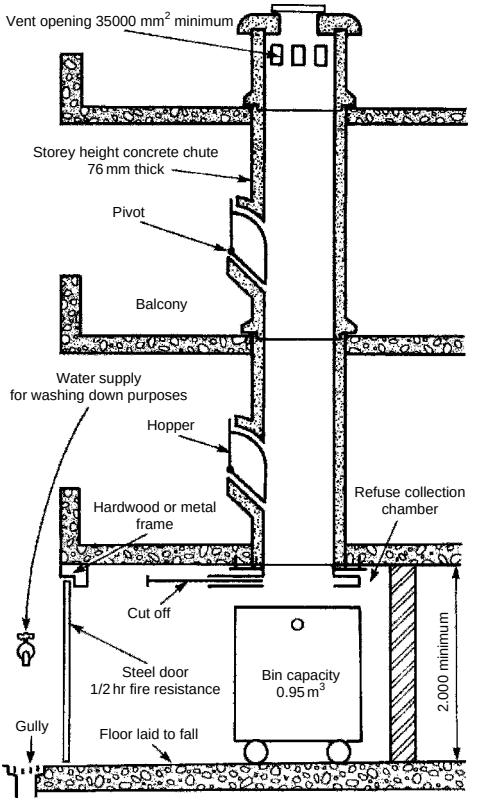
Combined surface and foul water drains will require separate calculations for both flow conditions. Drain size can be based on the greater flow, not the total flow as the chance of the peak flows of both coinciding is remote.

See pages 329 and 330 for alternative 'K' factor method of drainage design.

The quantity and location of refuse chutes depends upon:

- layout of the building
- number of dwellings served – max. six per hopper
- type of material stored
- frequency of collection
- volume of refuse
- refuse vehicle access – within 25 m.

The chute should be sited away from habitable rooms, but not more than 30 m horizontal distance from each dwelling. It is more economical to provide space for additional storage beneath the chute, than to provide additional chutes. Chute linings are prefabricated from refractory or Portland cement concrete with a smooth and impervious internal surface. The structure containing the chute void should have a fire resistance of 1 hour. The refuse chamber should also have a 1 hour fire resistance and be constructed with a dense impervious surface for ease of cleaning.

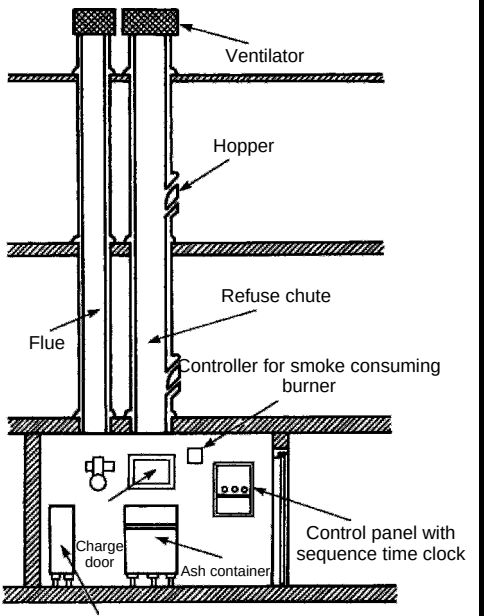


The chute should be circular on plan with a minimum i.d. of 450 mm

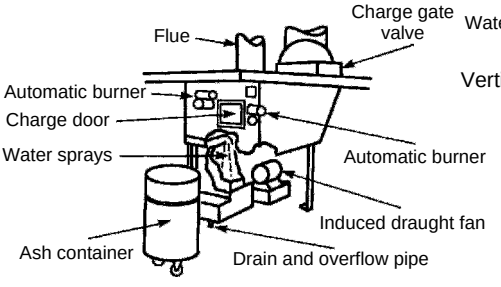
Ref: BS 5906: Waste management in buildings. Code of practice.

This system has a flue to discharge the incinerated gaseous products of combustion above roof level. A fan ensures negative pressure in the discharge chute to prevent smoke and fumes being misdirected. A large combustion chamber receives and stores the refuse until it is ignited by an automatic burner. Duration of burning is thermostatically and time controlled. Waste gases are washed and cleaned before discharging into the flue. There is no restriction on wet or dry materials, and glass, metal or plastics may be processed.

Health risks associated with storing putrefying rubbish are entirely eliminated as the residue from combustion is odourless and sterile. Refuse removal costs are reduced because the residual waste is only about 10% of the initial volume.

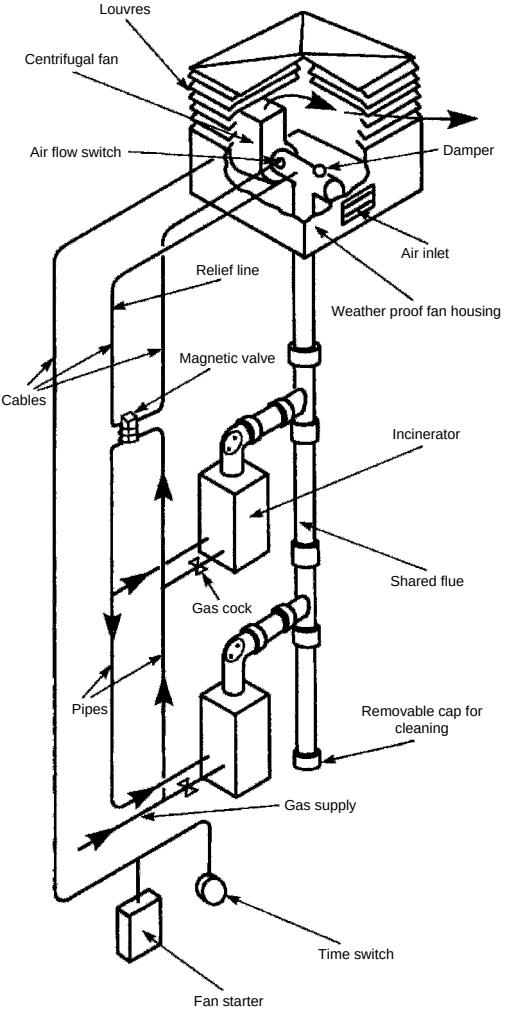


Vertical section of refuse disposal system



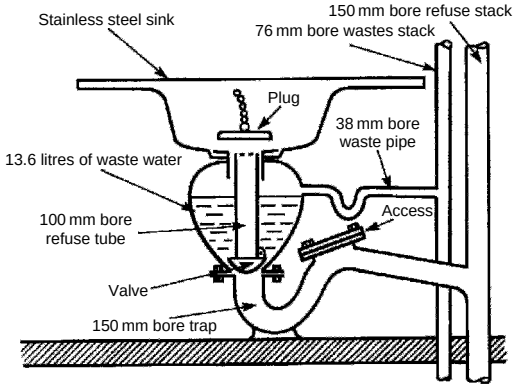
View of incinerator

Incinerators are the quickest, easiest and most hygienic method for disposing of dressings, swabs and sanitary towels. They are usually installed in office lavatories, hospitals and hotels. When the incinerator door is opened, gas burners automatically ignite and burn the contents. After a pre-determined time, the gas supply is cut off by a time switch. Each time the door is opened, the time switch reverts to its original position to commence another burning cycle. Incinerators have a removable ash pan and a fan assisted flue to ensure efficient extraction of the gaseous combustion products. In event of fan failure, a sensor ensures that gas burners cannot function. The gas pilot light has a thermocoupled flame failure device.

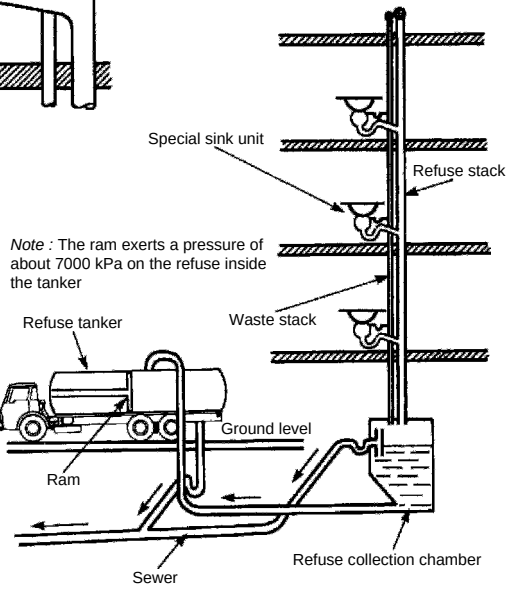


Diagrammatic layout of system

Food waste, bottles, cans and cartons are disposed of at source, without the need to grind or crush the refuse. A bowl beneath the sink retains the normal waste water. Refuse is placed inside a central tube in the sink. When the tube is raised the waste water and the refuse are carried away down a stack or discharge pipe to a chamber at the base of the building. Refuse from the chamber is collected at weekly intervals by a specially equipped tanker in which the refuse is compacted into a damp, semi-solid mass that is easy to tip. One tanker has sufficient capacity to contain the refuse from up to 200 dwellings. Waste water from the tanker is discharged into a foul water sewer.

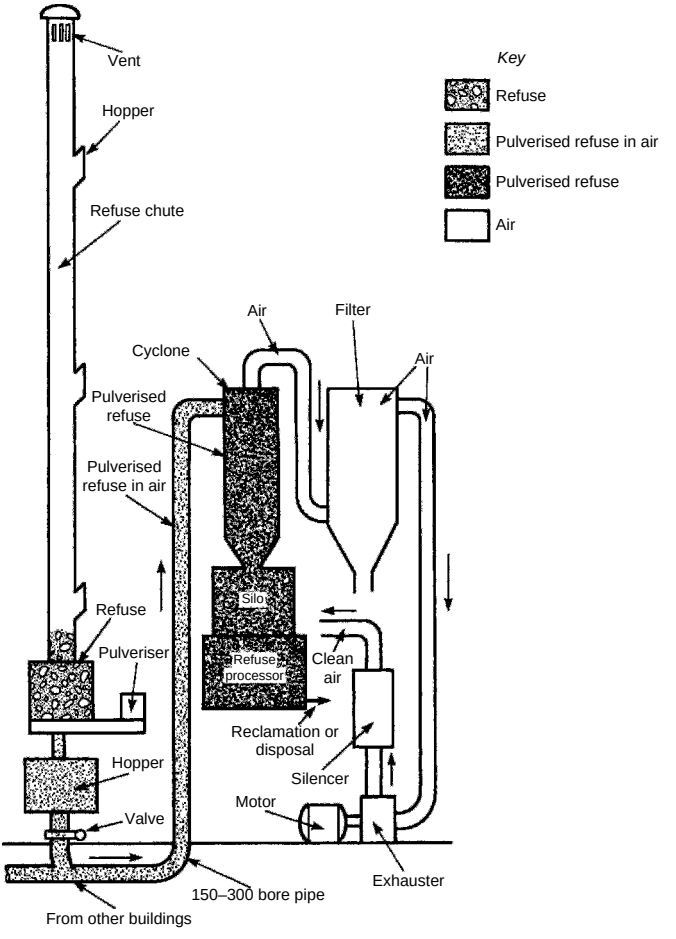


Detail of special sink unit



Layout of system

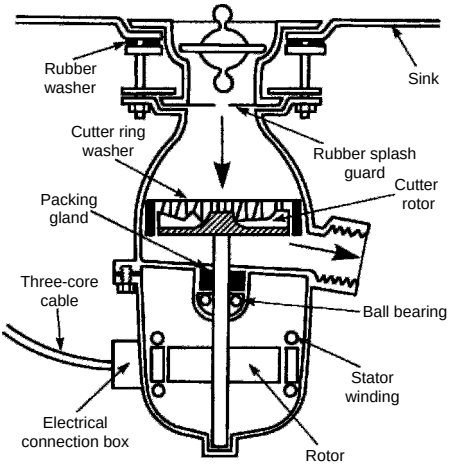
Refuse from conventional chutes is collected in a pulveriser and disintegrated by grinder into pieces of about 10 mm across. The refuse is then blown a short distance down a 75 mm bore pipe in which it is retained, until at pre-determined intervals a flat disc valve opens. This allows the small pieces of refuse to be conveyed by vacuum or airstream at 75 to 90 km/h through a common underground service pipe of 150–300 mm bore. The refuse collection silo may be up to 2·5 km from the source of refuse. At the collection point the refuse is transferred by a positive pressure pneumatic system to a treatment plant where dust and other suspended debris is separated from bulk rubbish. The process can be adapted to segregate salvagable materials such as metals, glass and paper.



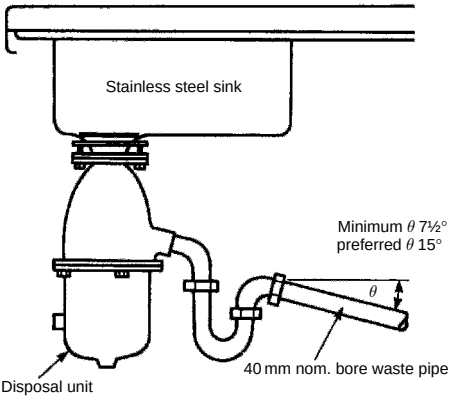
Diagrammatic layout of the system

Food waste disposal units are designed for application to domestic and commercial kitchen sinks. They are specifically for processing organic food waste and do not have the facility to dispose of glass, metals, rags or plastics. Where a chute or Garchey system is not installed, these units may be used to reduce the volume otherwise deposited in dustbins or refuse bags.

Food waste is fed through the sink waste outlet to the unit. A grinder powered by a small electric motor cuts the food into fine particles which is then washed away with the waste water from the sink. The partially liquefied food particles discharge through a standard 40 mm nominal bore waste pipe into a back inlet gully. As with all electrical appliances and extraneous metalwork, it is essential that the unit and the sink are earthed.



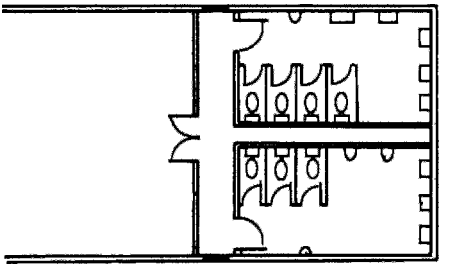
Section through unit



Waste pipe arrangement

Ref. BS EN 60335-2-16: Specification for safety of household and similar electrical appliances. Particular requirements for food waste disposers.

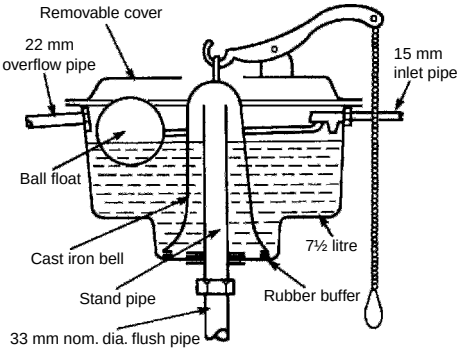
8 SANITARY FITMENTS AND APPLIANCES: DISCHARGE AND WASTE SYSTEMS



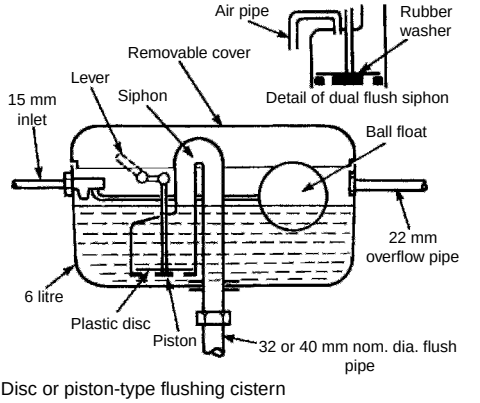
FLUSHING CISTERNS, TROUGHS AND VALVES
WATER CLOSETS
BIDETS
SHOWERS
BATHS
SINKS
WASH BASINS AND TROUGHS
URINALS
HOSPITAL SANITARY APPLIANCES
SANITARY CONVENIENCES AND ACTIVITY SPACE
FACILITIES FOR THE DISABLED
TRAPS AND WASTE VALVE
SINGLE STACK SYSTEM AND VARIATIONS
ONE- AND TWO-PIPE SYSTEMS
PUMPED WASTE SYSTEM
WASH BASINS – WASTE ARRANGEMENTS
WASHING MACHINE AND DISHWASHER WASTES
AIR TEST
SANITATION – DATA
GROUND FLOOR APPLIANCES – HIGH RISE BUILDINGS
FIRE STOPS AND SEALS
FLOW RATES AND DISCHARGE UNITS
SANITATION DESIGN – DISCHARGE STACK SIZING

Bell type – this form of flushing cistern is now virtually obsolete, although some reproductions are available for use in keeping with refurbishment of historic premises. Cast iron originals may still be found in use in old factories, schools and similar established buildings. It is activated by the chain being pulled which also lifts the bell. As the chain is released the bell falls to displace water down the stand pipe, effecting a siphon which empties the cistern. The whole process is relatively noisy.

Disc type – manufactured in a variety of materials including plastics and ceramics for application to all categories of building. Depressing the lever raises the piston and water is displaced over the siphon. A siphonic action is created to empty the cistern. Some cisterns incorporate an economy or dual flush siphon. When the lever is depressed and released promptly, air passing through the vent pipe breaks the siphonic action to give a 4·5 litre flush. When the lever is held down a 7·5 litre flush is obtained. Since 2001 the maximum permitted single flush to a WC pan is 6 litres.



Bell-type flushing cistern (obsolete)

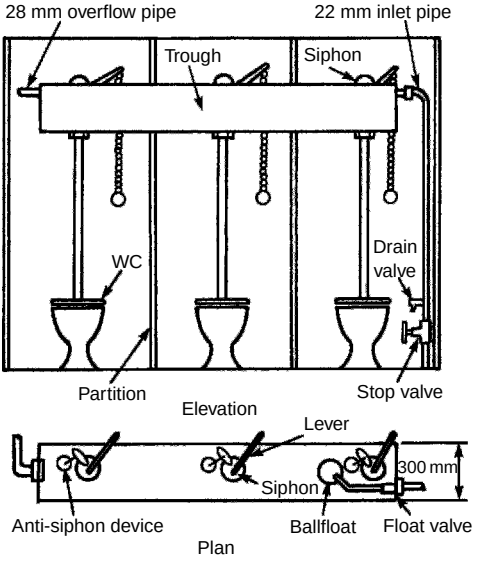


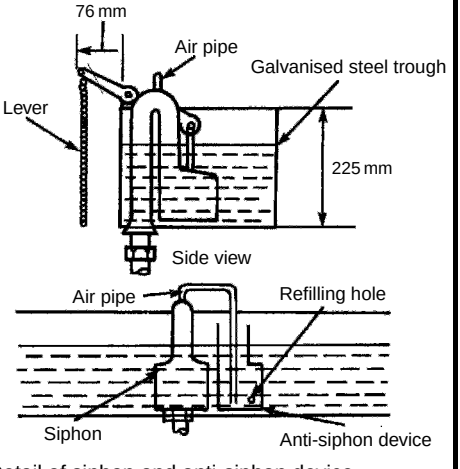
Disc or piston-type flushing cistern

Refs: BS 1125 and 7357: Specifications for WC flushing cisterns.
The Water Supply (Water Fittings) Regulations 1999.

A flushing trough may be used as an alternative to several separate flushing cisterns where a range of WCs are installed. They are particularly applicable to school, factory and office sanitary accommodation. Trough installation is economic in equipment and time. It is also more efficient in use as there is no waiting between consecutive flushes. The disadvantage is that if it needs maintenance or repair, the whole range of WCs are unusable. The trough may be bracketed from the rear wall and hidden from view by a false wall or ceiling.

The siphon operates in the same manner as in a separate cistern, except that as water flows through the siphon, air is drawn out of the air pipe. Water is therefore siphoned out of the anti-siphon device, the flush terminated and the device refilled through the small hole.

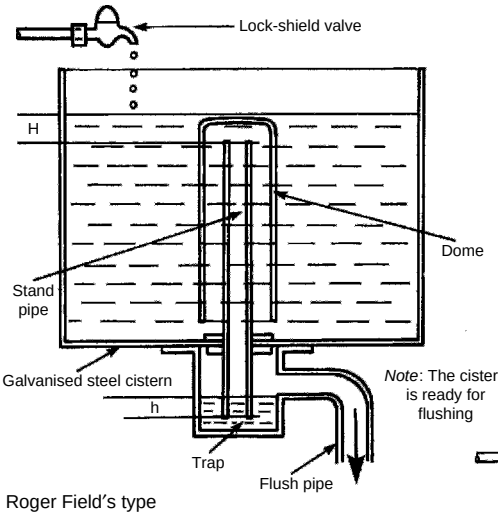




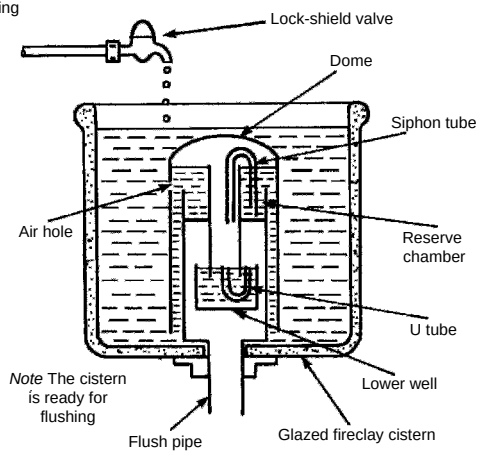
Detail of siphon and anti-siphon device

Roger Field's flushing cistern is used for automatically flushing WCs. It has application to children's lavatories and other situations where the users are unable to operate a manual flush device. As the cistern fills, air in the stand pipe is gradually compressed. When the head of water `H' is slightly above the head of water `h', water in the trap is forced out. Siphonic action is established and the cistern flushes the WC until air enters under the dome to break the siphon.

With the smaller urinal flush cistern, water rises inside the cistern until it reaches an air hole. Air inside the dome is trapped and compressed as the water rises. When water rises above the dome, compressed air forces water out of the U tube. This lowers the air pressure in the stand pipe creating a siphon to empty the cistern. Water in the reserve chamber is siphoned through the siphon tube to the lower well.

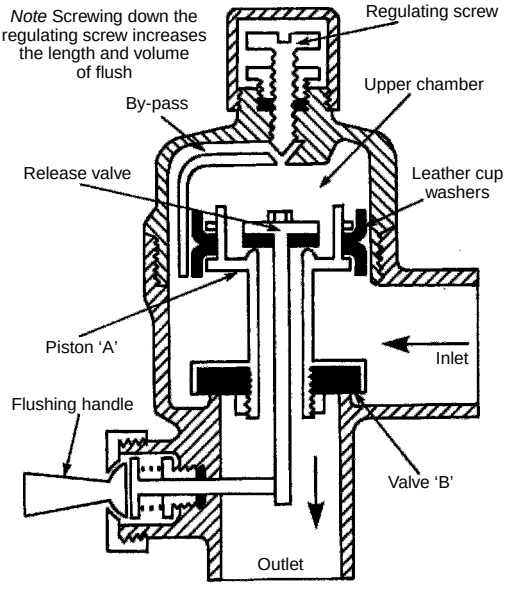


Roger Field's type

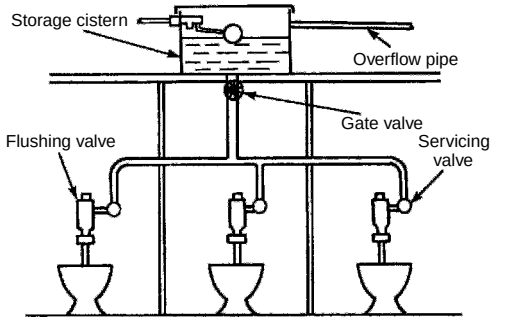


Smaller type for urinals

Flushing valves are a more compact alternative to flushing cisterns, often used in marine applications, but may only be used in buildings with approval of the local water authority. The device is a large equilibrium valve that can be flushed at any time without delay, provided there is a constant source of water from a storage cistern. The minimum and maximum head of water above valves is 2·2 m and 36 m respectively. When the flushing handle is operated, the release valve is tilted and water displaced from the upper chamber. The greater force of water under piston `A´ lifts valve `B´ from its seating and water flows through the outlet. Water flows through the by-pass and refills the upper chamber to cancel out the upward force acting under piston `A´. Valve `B´ closes under its own weight.

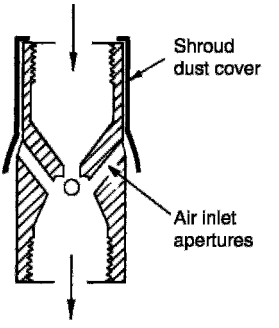


Section through flushing valve

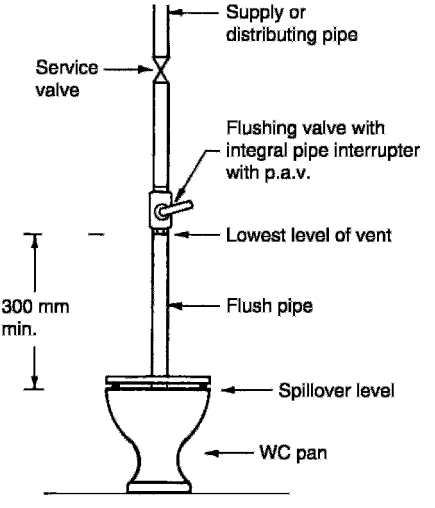


Installation of flushing valve

- The minimum flow rate at an appliance is 1·2 litres per second. By domestic standards this is unrealistically high, therefore pressure flushing valves are not permitted in houses.
- Where connected to a mains supply pipe or a cistern distributing pipe, a flushing valve must include a backflow prevention device having a permanently vented pipe interrupter situated at least 300 mm above the spillover level of the served WC.
- If a permanently vented pipe interrupter is not fitted, the water supply to a flushing valve must be from a dedicated cistern with an air gap (see page 19) below its float valve delivery.
- The maximum flush in a single operation is 6 litres.
- Flushing valves may be used to flush urinals. In this situation they should deliver no more than 1·5 litres of water to each bowl or position per operation. See page 299.



Pipe interrupter with a permanent atmospheric vent

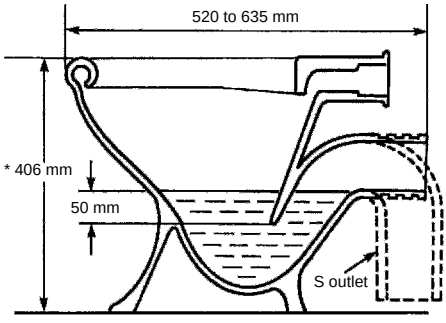


WC with flushing valve

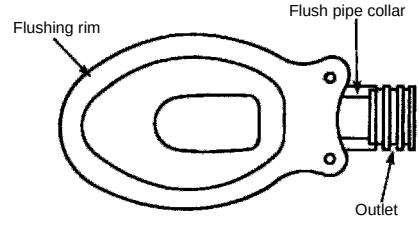
The washdown WC pan is economic, simple and efficient. It rarely becomes blocked and can be used in all types of buildings with colour variations to suit internal decor. Manufacture is primarily from vitreous china, although glazed fireclay and stoneware have been used. Stainless steel WCs can be specified for use in certain public areas and prisons. Pan outlet may be horizontal, P, S, left or right handed. Horizontal outlet pans are now standard, with push-fit adaptors to convert the pan to whatever configuration is required. Plastic connectors are commonly used for joining the outlet to the soil branch pipe. The flush pipe joint is usually made with a rubber cone connector which fits tightly between WC and pipe.

WC pan outlet < 80 mm, trap diameter = 75 mm

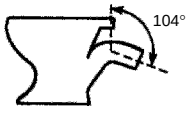
WC pan outlet > 80 mm, trap diameter = 100 mm



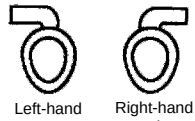
Section of horizontal outlet pan



Plan

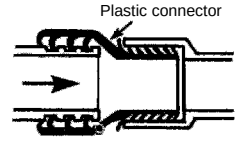


P type outlet

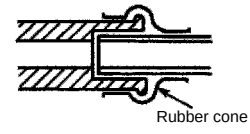


Left-hand outlet

Right-hand outlet



Plastic outlet joint



Rubber flush pipe joint

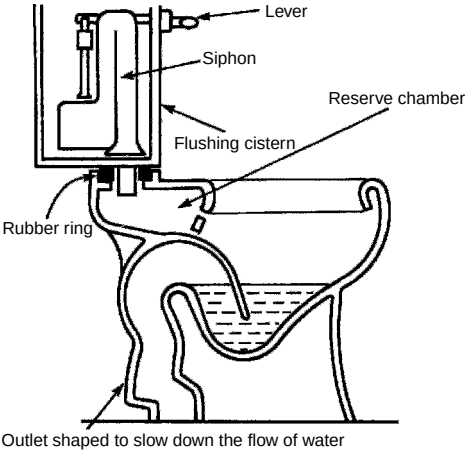
*Note: Add approximately 25 mm to the top of the WC to allow for seat height. Overall height for disabled is 480 mm, junior school children 355 mm and infants 305 mm.

Refs: BS 5504-1: Wall hung WC pan.
BS EN 997: WC pans and WC suites with integral trap.

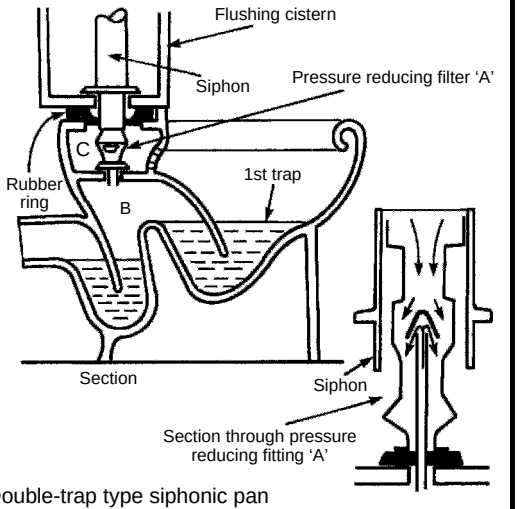
Siphonic WCs are much quieter in operation than washdown WCs and they require less flush action to effect an efficient discharge. They are not suitable for schools, factories and public buildings as they are more readily blocked if not used carefully.

The double trap type may be found in house and hotel bathrooms. When flushed, water flows through the pressure reducing fitting `A'. This reduces the air pressure in chamber `B'. Siphonic action is established and the contents of the first trap are removed. This is replenished from reserve chamber `C'.

The single trap variant is simpler and has limited application to domestic bathrooms. When the cistern is flushed, the content is discharged through the trap and restricted in flow by the specially shaped pan outlet pipe. The pipe fills with water which causes a siphonic effect. Sufficient water remains in the reserve chamber to replenish the seal.

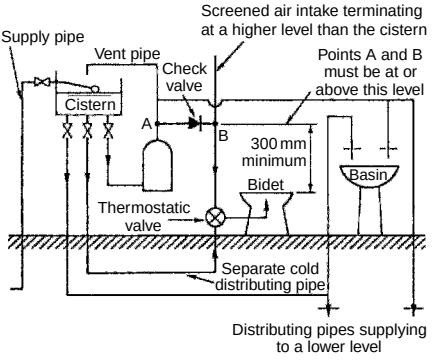


Single-trap type siphonic pan

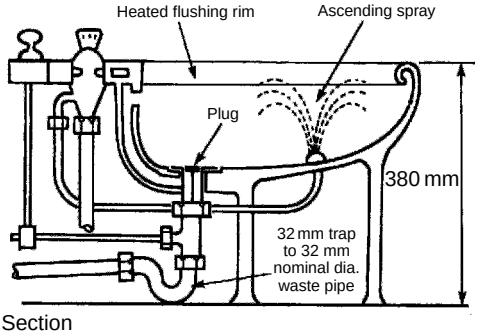


Double-trap type siphonic pan

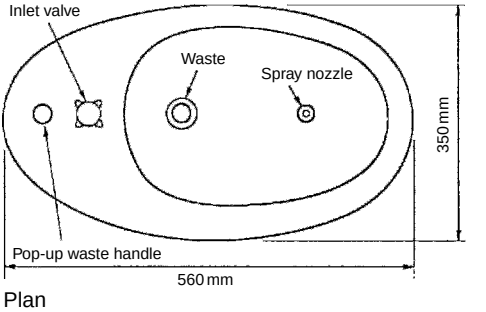
A bidet is classified as a waste fitting. The requirements for a discharge pipe from a bidet may therefore be treated in the same manner as a basin waste of the same diameter – nominally 32 mm. It is an ablutionary fitting used for washing the excretory organs, but may also be used as a foot bath. Hot and cold water supplies are mixed to the required temperature for the ascending spray. For greater comfort the rim of the fitting may be heated from the warm water. Ascending spray type bidets are not favoured by the water authorities because the spray nozzle is below the spill level, risking water being back-siphoned into other draw off points. This is prevented by having independent supply pipes to the bidet which are not connected to any other fittings. A further precaution would be installation of check valves on the bidet supply pipes or a thermostatic regulator with integral check valves. Over the rim hot and cold supplies are preferred with an air gap (see page 19) between rim and tap outlets.



Installation pipework for bidet



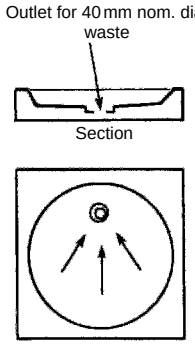
Section



Plan

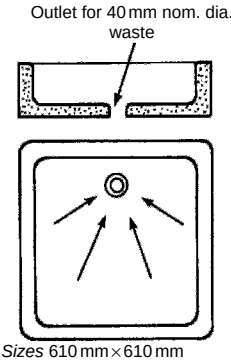
Ref: BS 5505: Specification for bidets.

A shower is more economic to use than a bath as it takes less hot water (about one-third), it is arguably more hygienic and it takes up less space. The mixing valve should be thermostatic (see pages 293 to 296) to avoid the risk of scalding. A minimum 1 m head of water should be allowed above the shower outlet. If this is impractical, a pumped delivery could be considered (see next page). The shower outlet (rose) should also be at least 2 m above the floor of the shower tray. Supply pipes to individual showers are normally 15 mm o.d. copper or equivalent. These should incorporate double check valves if there is a flexible hose to the rose, as this could be left in dirty tray water which could back-siphon. An exception to check valves is where the shower head is fixed and therefore well above the air gap requirements and spill over level of the tray.



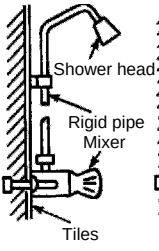
Sizes 750 mm × 750 mm
800 mm × 800 mm

Acrylic shower tray

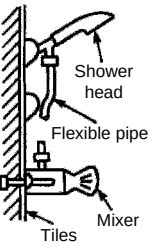


Sizes 610 mm × 610 mm
760 mm × 760 mm
815 mm × 815 mm
915 mm × 915 mm

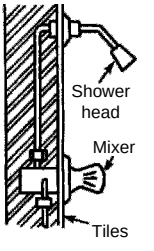
Enamelled fireclay shower tray



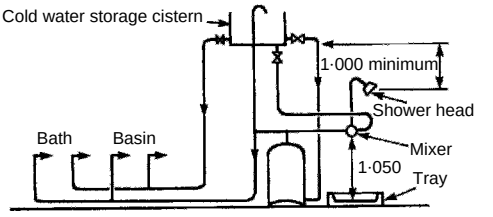
Rigid pipe on tile face



Flexible pipe on tile face



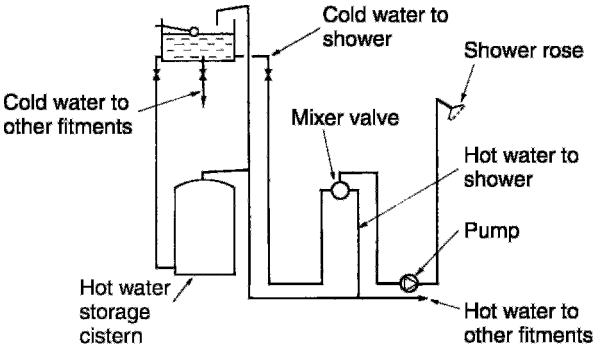
Rigid pipe at back of tiles



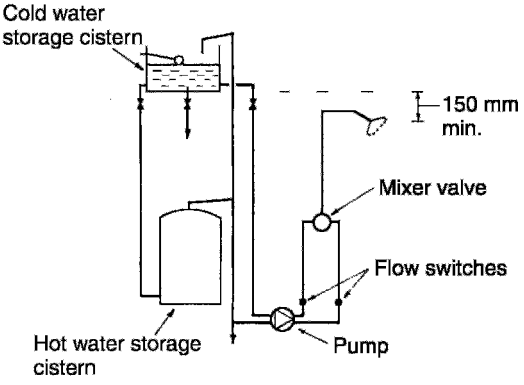
Installation pipework for shower

Refs: BS EN 251: Shower trays. Connecting dimensions.
BS 6340: Shower units (various specifications).
BS EN 263: Cross-linked cast acrylic sheets for baths and shower trays for domestic purposes.

Where the 1 m minimum head of water above the shower outlet is not available and it is impractical to raise the level of the supply cistern, a pump can be fitted to the mixer outlet pipe or on the supply pipes to the mixer. The pump is relatively compact and small enough to be installed on the floor of an airing cupboard or under the bath. It must be accessible for maintenance, as the pump should be installed with filters or strainers which will require periodic attention, particularly in hard water areas. The pump will operate automatically in response to the shower mixer being opened. A pressure sensor and flow switch detect water movement to activate the pump and vice versa. Electricity supply can be from an isolating switch or pull cord switch with a 3 amp fuse overload protection spurred off the power socket ring main.



Pump on mixed water outlet



Pumped supply to mixer

Note: Double check valves may be required on the supply pipes as described on the previous page. The mixing valve and pump may incorporate check valves – refer to manufacturer's information.

Mains Fed, Electric Shower – 1

Instantaneous electric water heating for showers is an economic, simple to install alternative to a pumped shower. This is particularly apparent where there would otherwise be a long secondary flowpipe from the hot water storage cylinder to the shower outlet, possibly requiring additional secondary return pipework to avoid a long 'dead leg'. Cold water supply is taken from the rising main in 15 mm o.d. copper tube. This will provide a regulated delivery through the shower unit of up to 3 litres/min. The unit contains an electric element, usually of 7·2 or 8·4 kW rating. It also has a number of built-in safety features:

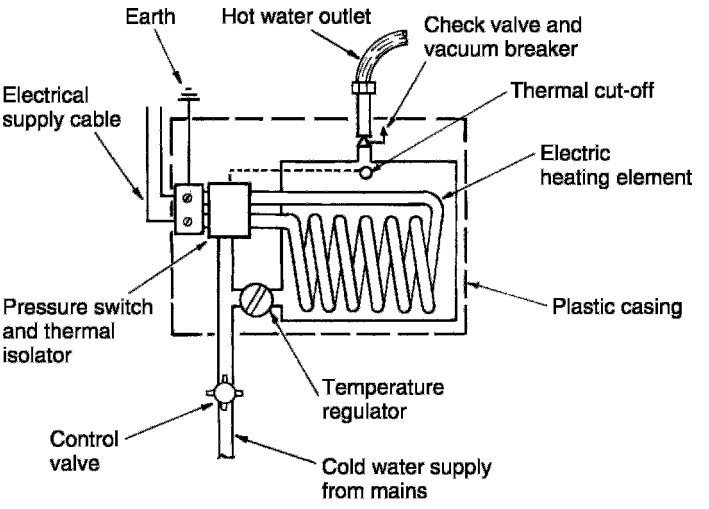
- Automatic low pressure switch to isolate the element if water pressure falls significantly or the supply is cut off.
- Thermal cut-off. This is set by the manufacturer at approximately 50°C to prevent the water overheating and scalding the user.
- Non-return or check valve on the outlet to prevent back-siphonage.

Electricity supply is an independent radial circuit, originating at the consumer unit with a miniature circuit breaker (MCB) appropriately rated. Alternatively a suitable rated fuse way may be used in the consumer unit and added protection provided with an in-line residual current device (RCD) trip switch. All this, of course, is dependent on there being a spare way in the consumer unit. If there is not, there will be additional expenditure in providing a new consumer unit or a supplementary fuse box. A double pole cord operated pull switch is located in the shower room to isolate supply.

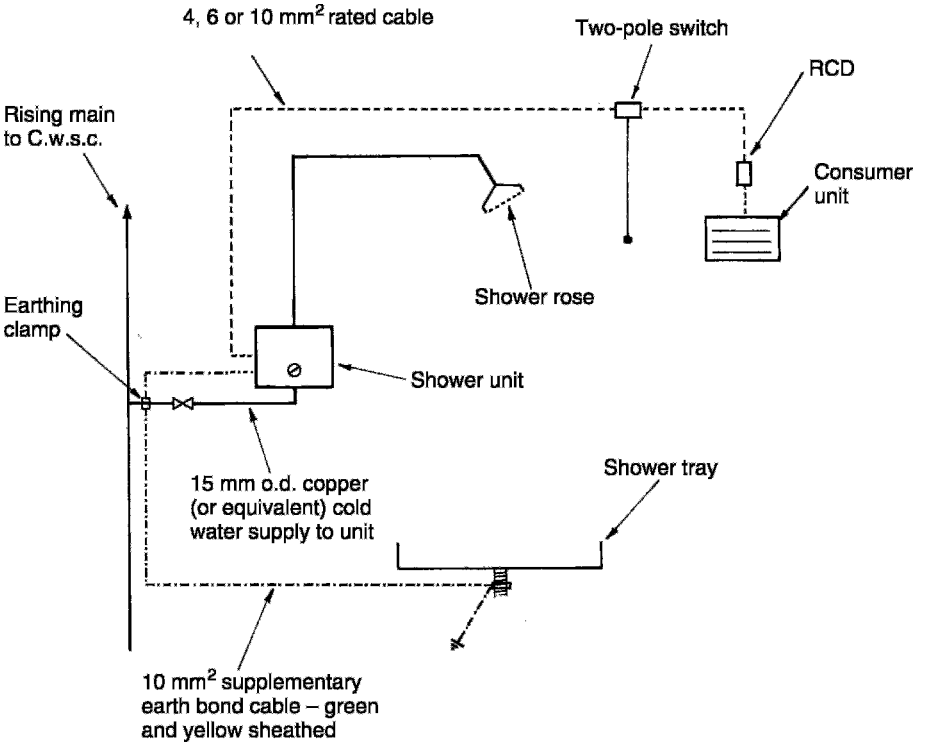
Shower rating (kW)	Cable length (m)	Fuse of MCB rating (amps)	Cable size (mm^2)
7·2	<13	30 or 32	4
7·2	13–20	30 or 32	6
7·2	20–35	30 or 32	10
8·4	<17	40 or 45	6
8·4	17–28	40 or 45	10

Ref: BS 6340: Shower units (various specifications).

Unit detail and installation:



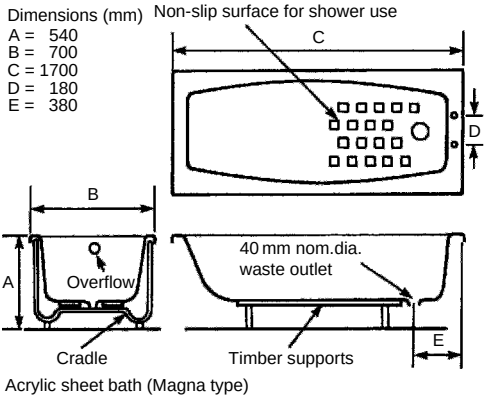
Instantaneous shower water heater



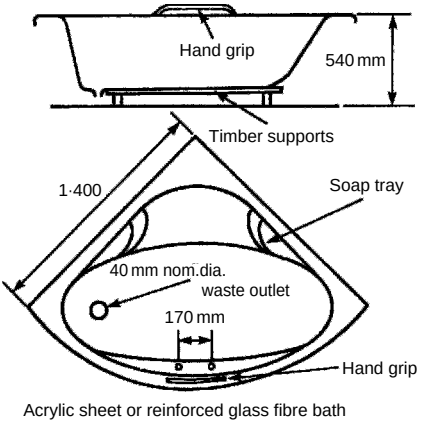
Installation of water supply and electricity

Baths are manufactured in acrylic sheet, reinforced glass fibre, enamelled pressed steel and enamelled cast iron. The acrylic sheet bath has the advantage of light weight to ease installation, it is comparatively inexpensive and is available in a wide range of colours. However, special cleaning agents must be used otherwise the surface can become scratched. It will require a timber support framework, normally laid across metal cradles. Traditional cast iron baths are produced with ornate feet and other features. Less elaborate, standard baths in all materials can be panelled in a variety of materials including plastic, veneered chipboard and plywood.

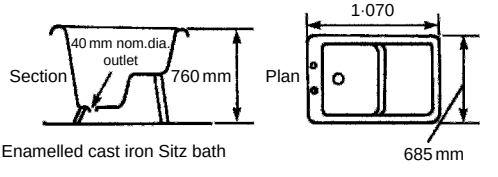
The corner bath is something of a luxury. It may have taps located to one side to ease accessibility. A Sitz bath is stepped to form a seat. It has particular application to nursing homes and hospitals for use with the elderly and infirm.



Acrylic sheet bath (Magna type)



Acrylic sheet or reinforced glass fibre bath

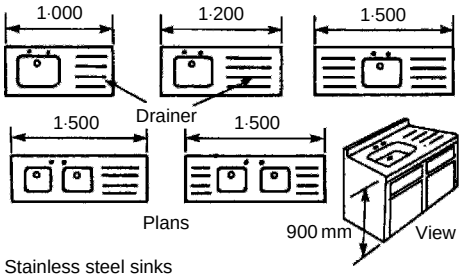


Enamelled cast iron Sitz bath

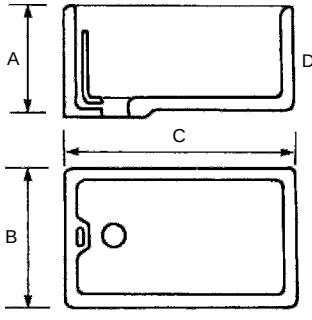
Refs: BS 1189 and 1390: Specifications for baths made from porcelain enamelled cast iron and vitreous enamelled sheet steel, respectively.
BS 4305: Baths for domestic purposes made of acrylic material.
BS EN 232: Baths. Connecting dimensions.

Sinks are designed for culinary and other domestic uses. They may be made from glazed fireclay, enamelled cast iron or steel, stainless steel or from glass fibre reinforced polyester.

The Belfast sink has an integral weir overflow and water may pass through this to the waste pipe via a slotted waste fitting. It may have a hardwood or dense plastic draining board fitted at one end only or a draining board fitted on each end. Alternatively, the sink may be provided with a fluted drainer of fireclay. The London sink has similar features, but it does not have an integral overflow. In recent years sinks of this type have lost favour to surface built-in metal and plastic materials, but there is now something of a resurgence of interest in these traditional fittings. Stainless steel sinks may have single or double bowls, with left- or right-hand drainers or double drainers. These can be built into a work surface or be provided as a sink unit with cupboards under. The waste outlet is a standard 40 mm nominal diameter.



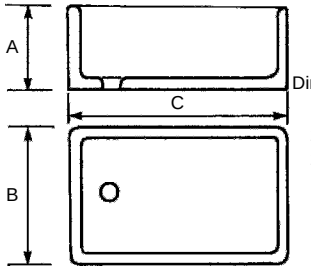
Stainless steel sinks



Dimensions (mm)

A	B	C
305	610	915
255	455	760
255	455	610
255	405	610
255	405	535
200	455	610
200	405	610
200	380	455

Enamelled fireclay Belfast sink



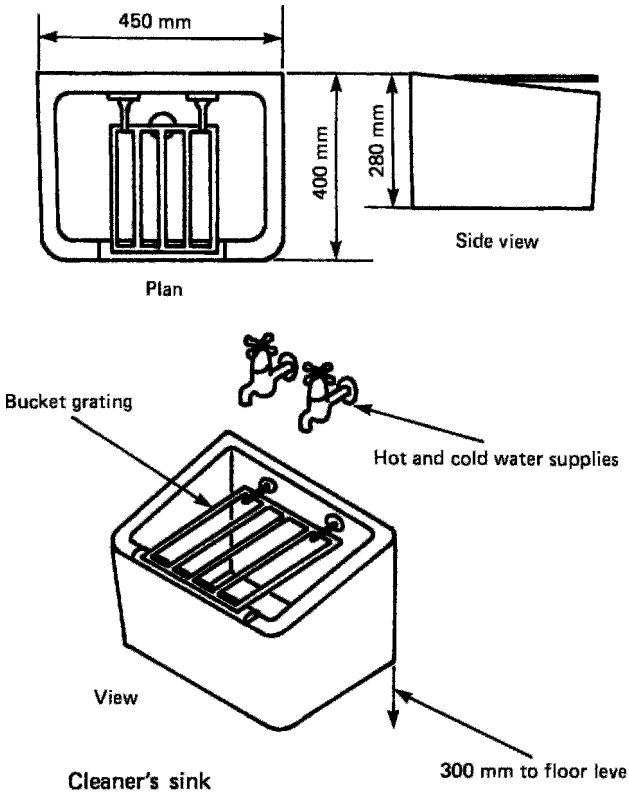
Dimensions (mm)

A	B	C
255	455	610
200	380	455

Enamelled fireclay London sink

Refs: BS 1206: Specification for fireclay sinks, dimensions and workmanship.
BS EN 13310: Kitchen sinks. Functional requirements and test methods.

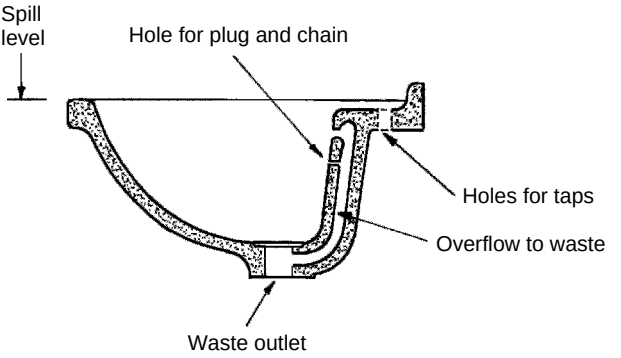
These are rarely necessary in domestic situations, but have an application to commercial premises, schools, hospitals and similar public buildings. They are usually located inside the cleaning contractor's cubicle and are fitted at quite a low level to facilitate ease of use with a bucket. They are normally supported by built-in cantilever brackets and are additionally screwed direct to the wall to prevent forward movement. 13 mm bore (half inch) hot and cold water draw off bib-taps may be fitted over the sink, at sufficient height for a bucket to clear below them. 19 mm bore (three-quarter inch) taps may be used for more rapid flow. A hinged stainless steel grating is fitted to the sink as a support for the bucket. The grating rests on a hardwood pad fitted to the front edge of the sink to protect the glazed finish. A 40 mm nominal diameter waste pipe is adequate for this type of sink.



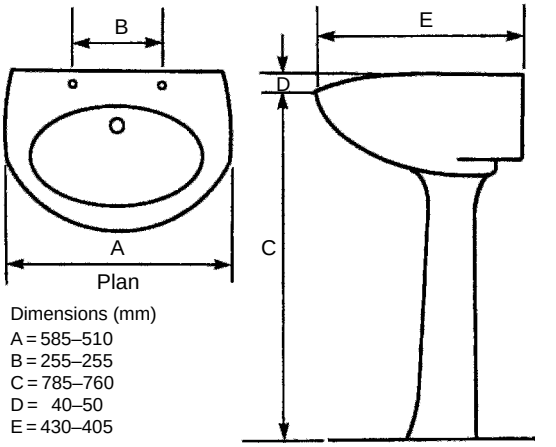
Cleaner's sink

There are various types of basin, ranging in size and function from hand rinsing to surgical use. A standard basin for domestic application to bathrooms and cloakrooms consists of a bowl, soap tray, weir overflow and holes for taps and outlet. It may be supported by cast iron brackets screwed to the wall, a corbel which is an integral part of the basin built into the wall or a floor pedestal which conceals the pipework. Water supply is through 13 mm (half inch) pillar taps for both hot and cold. A standard 32 mm nominal diameter waste outlet with a slot to receive the integral overflow connects to a trap and waste pipe of the same diameter. A plug and chain normally controls outflow, but some fittings have a pop-up waste facility.

Most basins are made from coloured ceramic ware or glazed fireclay. There are also metal basins produced from stainless steel, porcelain enamelled sheet steel or cast iron.



Section through a typical basin

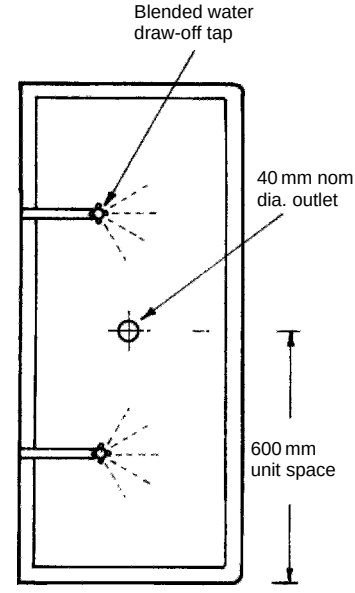


Dimensions (mm)
A = 585–510
B = 255–255
C = 785–760
D = 40–50
E = 430–405

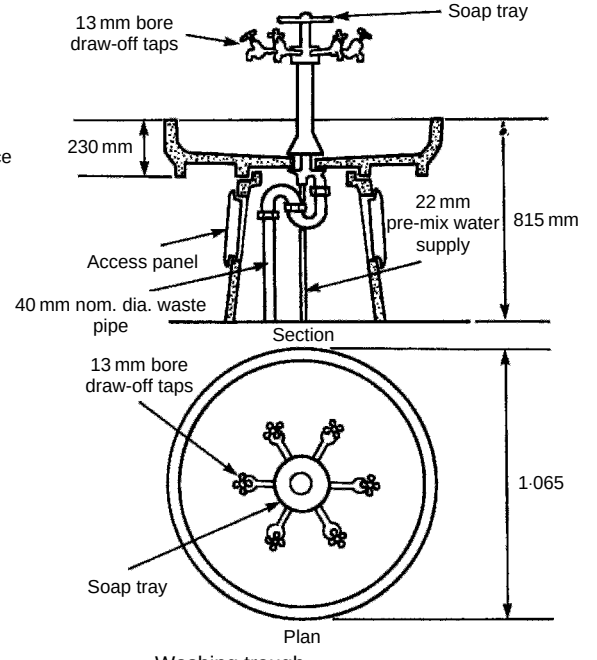
Wash basin

Refs: BS 1329: Specification for metal hand rinse basins.
BS 1188: Specification for ceramic wash basins and pedestals.
BS 5506-3: Specification for wash basins.

Washing troughs are manufactured circular or rectangular on plan in ceramic materials or stainless steel. They are an economic and space saving alternative to a range of basins, for use in factory, school and public lavatories. Some variations have an overall umbrella spray or fountain effect operated by a foot pedal. These are no longer favoured by the water supply undertakings as a trough must have a separate draw-off tap for every placement. In common with other sanitary fitments, there must be provision to prevent the possibility of back-siphonage, i.e. an adequate air gap between tap outlet and spill level of the trough. Hot and cold water supply to the taps is thermostatically blended to about 45°C.



Straight washing trough (plan)



Washing trough

Safe water temperature – safety is considered from two perspectives:

1. Legionella or Legionnaires' disease –60 to 65°C stored hot water requirement to prevent development of the bacteria.
2. Scalding – water temperatures above 45°C can cause injury.

Recommended maximum temperatures at draw-off points are:

Appliance	Temperature °C
Bath	43
Shower	40
Hand basin	40
Bidet	37
Sink	48

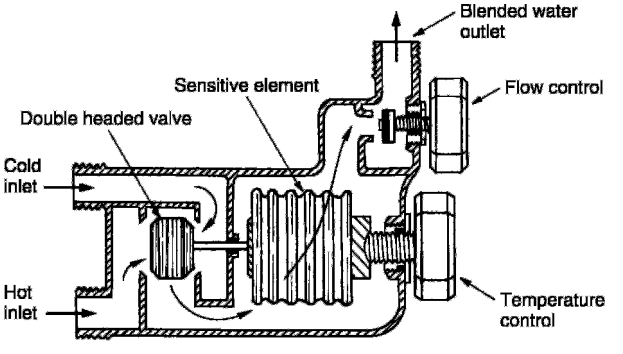
As can be seen, there is a conflicting temperature differential between the two perspectives of about 20°C. Therefore, scalding is possible unless measures are introduced to blend the hot water supply with cooler water.

Mixing valve types:

Type 1 (TMV 1) – mechanical mixing with an over temperature stop to BS EN 1286: Sanitary tapware. Low pressure mechanical mixing valves. General technical specification. Or, BS 5779: Specification for spray mixing taps.

Type 2 (TMV2) – thermostatic mixing to BS EN 1287: Sanitary tapware. Low pressure thermostatic mixing valves. General technical specification. Or, BS EN 1111: Sanitary tapware. Thermostatic mixing valves (PN 10). General technical specification.

Type 3 (TMV 3) – thermostatic mixing with enhanced thermal performance. This should comply with NHS Estates Model Engineering Specification DO8, thermostatic mixing valves (healthcare premises).



Note: Water inlets at equal pressure

Thermostatic bellows mixing valve

In Scotland, any newly built property or any existing property subject to alterations or refurbishment that include bathroom facilities, must incorporate a device to prevent the hot water supply to a bath from exceeding 48°C. In due course, these Building Regulation requirements are likely to be implemented across the whole of the UK, along with reduced hot water temperatures at the outlets of other sanitary fitments. The need for these controls is in response to the unacceptably high number of scalding incidents through hot water supplied at normal storage temperature of about 60°C, as accounted for at the top of the preceding page.

This objective of safe hot water outlet temperatures can be achieved by installing a thermostatic mixing valve to blend cold and hot water supplies before they discharge through a terminal fitting, i.e. a tap or a shower rose. The basic mixing valve shown on the previous page has a temperature sensitive element that responds to inlet water temperature changes to ensure a stable outlet temperature. In addition to this blending facility, the outlet must also have an over-temperature detection element and valve to close the delivery if the cold water supply fails or if the sensitive element within the mixing unit malfunctions.

Thermostatic mixing valves to TMV1 specification have largely been superseded by the higher expectations of TMV2 standards. However, the TMV1 specification is still acceptable in situations where persons using the blended water supply are not considered to be at any risk. This generally excludes use in premises occupied by children, elderly or infirm people. Valves to TMV2 specifications will normally satisfy the standards expected for domestic use, i.e. installation in dwellings, housing association properties, hotels and hostels. Valves to TMV3 specification are for higher risk situations, such as nursing/ convalescent homes and hospitals.

Further references:

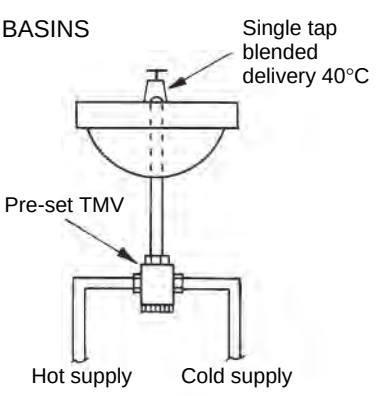
Building Regulations Part G: Hygiene.

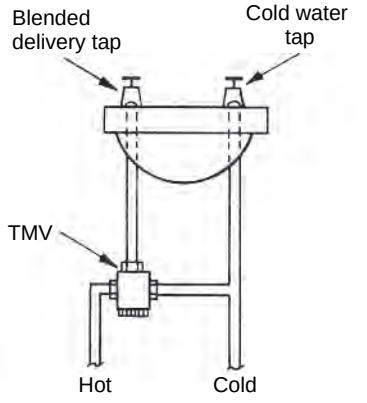
Building Research Establishment, Information Paper IP 14/03, Preventing hot water scalding in bathrooms: using TMVs.

BS 7942: Thermostatic mixing valves for use in care establishments.

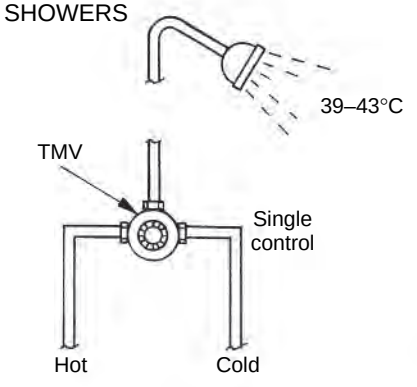
Typical applications

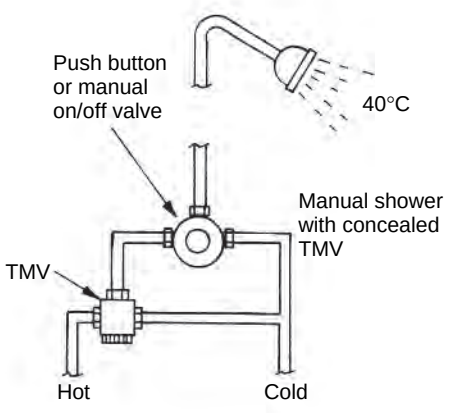
BASINS



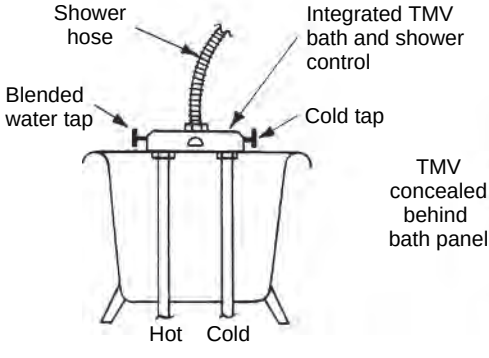


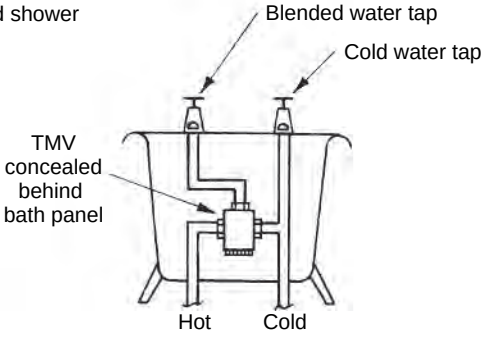
SHOWERS



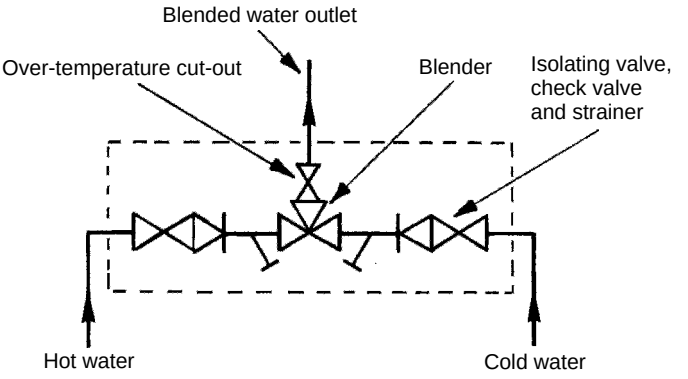


BATHS



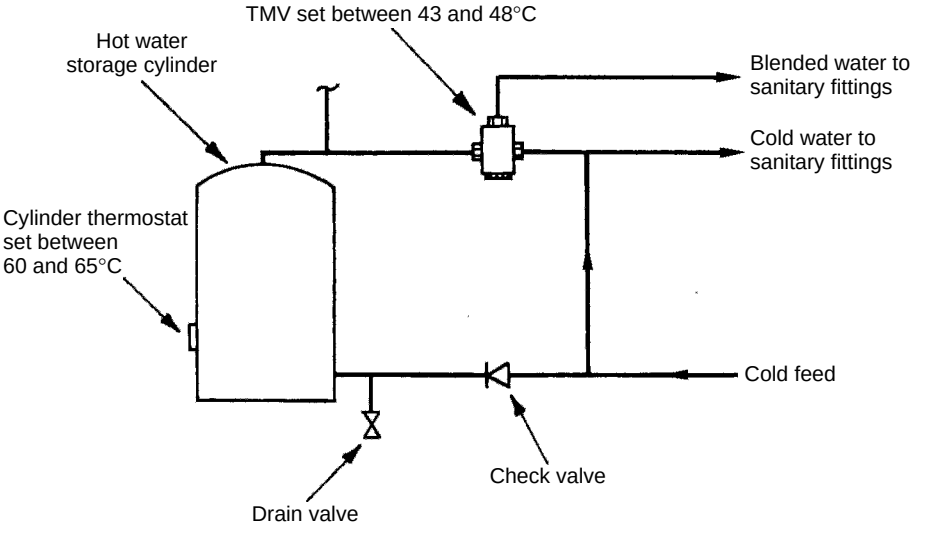


Typical TMV unit



The stored hot water temperature must be at least 60°C to prevent the development of bacteria. Therefore, simply setting the hot water storage cylinder thermostat to provide a general supply of hot water at about 48°C is prohibited. Subject to the local water supply authority's requirements and approval, it may be possible to install just one central or master thermostatic mixing valve, to regulate domestic hot water requirements to all fitments as shown in principle, below.

Master mixing valve installation



When mixing hot water with cold water to provide a blended supply, the quantities and temperatures of each can be estimated relative to the required water temperature objective. Factors such as lengths of individual supply pipes, effect of pipe insulation if and where provided and slight variances in water density at different temperatures will make a nominal contribution and may be included for academic reasons. However, for practical purposes, the formula procedure shown below will provide an adequate approximation:

Heat lost by hot water supply = Heat gained by cold water supply

Heat lost by hot water supply = $q_1(t_h - t)$

Where: q_1 = quantity of hot water (litres or m^3)

t_h = temperature of hot water supply (°C)

t = temperature of mixed water (°C)

Heat gained by cold water supply = $q_2(t - t_c)$

Where: q_2 = quantity of cold water (litres or m^3)

t_c = temperature of cold water supply (°C)

t = temperature of mixed water (°C)

Therefore:

$$q_1(t_h - t) = q_2(t - t_c)$$

$$(q_1 \times t_h) - (q_1 \times t) = (q_2 \times t) - (q_2 \times t_c)$$

$$(q_1 \times t_h) + (q_2 \times t_c) = (q_2 \times t) + (q_1 \times t)$$

$$(q_1 \times t_h) + (q_2 \times t_c) = (q_2 \times q_1)t$$

$$\frac{(q_1 \times t_h) + (q_2 \times t_c)}{(q_2 + q_1)} = t$$

Example: A thermostatic mixing valve is set to blend hot water at 60°C with cold water at 8°C in the proportion of 2·5:1, i.e. 2·5 litres of hot water for every 1 litre of cold water. The resultant delivery temperature will be:

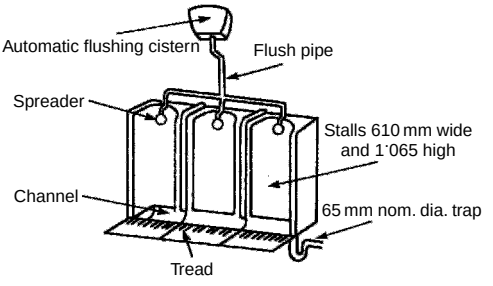
$$t = \frac{(2.5 \times 60) + (1 \times 8)}{(2.5 + 1)}$$

$$t = \frac{150 + 8}{3.5} = 45.14 \text{ approximately } 45^{\circ}C$$

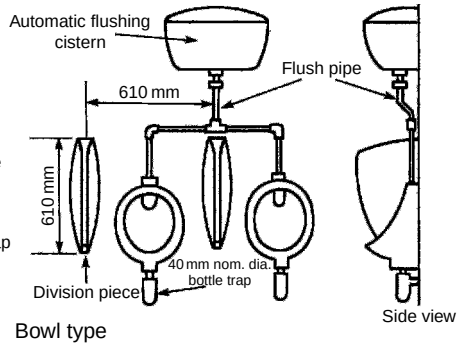
These are used in virtually all buildings and public lavatories containing common facilities for male conveniences. They reduce the need for a large number of WCs. Three formats are available in ceramic ware or stainless steel:

- Bowl – secured to the wall and provided with division pieces where more than one is installed.
- Flat slab – fixed against the wall with projecting return end slabs and a low level channel.
- Stall – contains curved stalls, dividing pieces and low level channel.

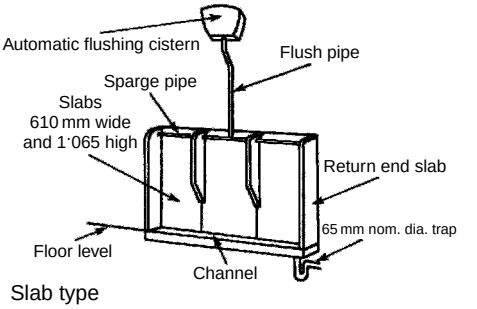
Urinals are washed at intervals of 20 minutes by means of an automatic flushing cistern discharging 4·5 litres of water per bowl of 610 mm of slab/stall width. The water supply to the cistern should be isolated by a motorised valve on a time control, to shut off when the building is not occupied. A hydraulically operated inlet valve to the automatic flushing cistern can be fitted. This closes when the building is unoccupied and other fittings not used.



Stall type



Bowl type



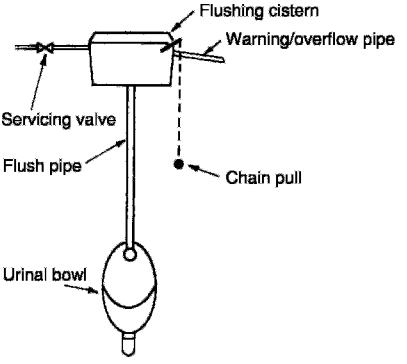
Slab type

Refs: BS 4880-1: Specification for urinals. Stainless steel slab urinals.
BS 5520: Specification for vitreous china bowl urinals.
BS EN 80: Wall hung urinals. Connecting dimensions.

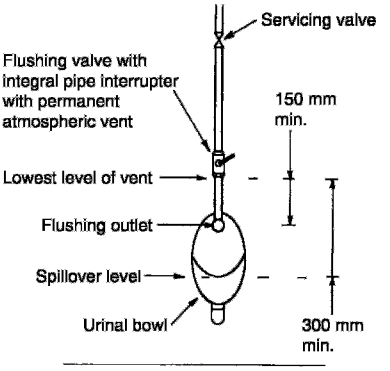
See page 278 and preceding page for automatic devices.

Urinals usually have automatically operated flushing mechanisms. However, manual operation is also acceptable by use of:

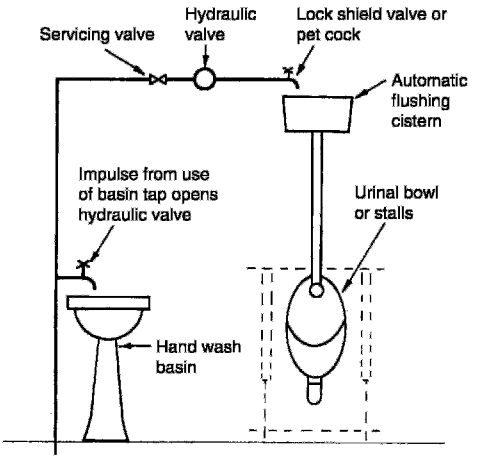
- Flushing cistern.
- Flushing valve.
- Wash basin tap and hydraulic valve (combination of manual and automatic).



Urinal with flushing cistern



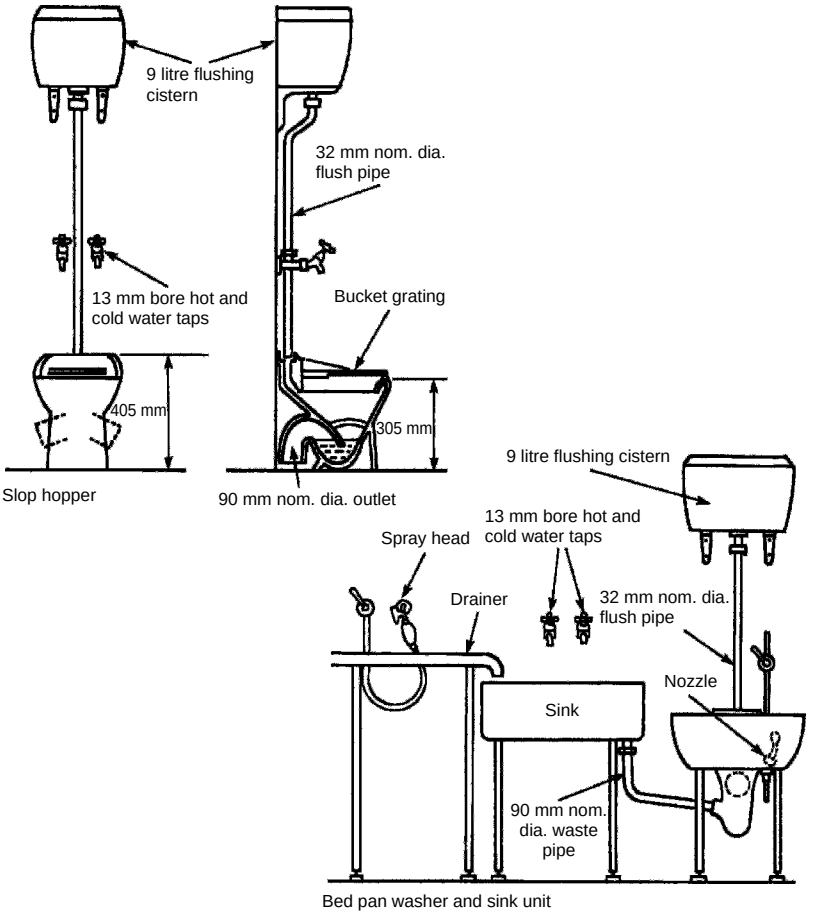
Urinal with flushing valve



Urinal with hydraulic valve

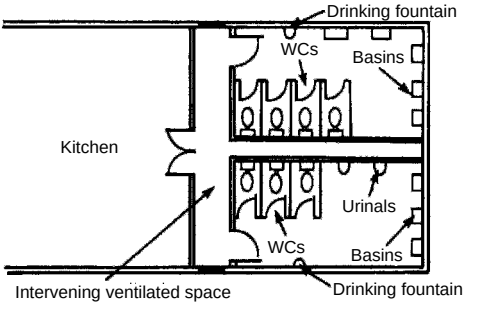
Special types of sanitary appliances are required for hospital sluice rooms. The slop hopper is used for the efficient disposal of bed pan excrement and general waste. It is similar in design to the washdown WC pan, but has a hinged stainless steel grating for a bucket rest. Another grating inside the pan prevents the entry of large objects which could cause a blockage.

The bed pan washer has a spray nozzle for cleaning bed pans and urine bottles. To prevent possible contamination of water supply, it is essential that the water supplying the nozzle is taken from an interposed cold water storage cistern used solely to supply the bed pan washer. Alternatively, the design of the bed pan washer must allow for an air gap (min. 20 mm) between spray outlet nozzle and water spill level. A 90 mm nominal diameter outlet is provided for the pan.

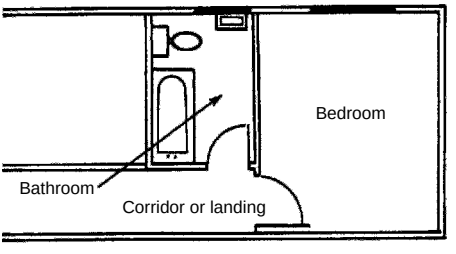


Bed pan washer and sink unit

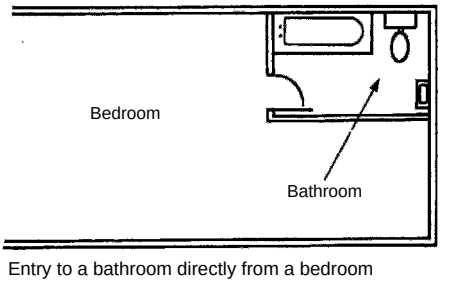
Approved Document G provides for minimum quantity, use and disposition of sanitary conveniences. These should contain sufficient appliances relative to a building's purpose and be separated from places where food is stored or prepared. Layout of appliances and installation should allow for access and cleaning. The diagrams illustrate various locations for sanitary conveniences, with an intermediate lobby or ventilated space as required. En-suite facilities are acceptable direct from a bedroom, provided another sanitary convenience is available in the building. All dwellings must have at least one WC and one wash basin. The wash basin should be located in the room containing the WC or in a room or space giving direct access to the WC room (provided that it is not used for the preparation of food). A dwelling occupying more than one family should have the sanitary facilities available to all occupants.



Sanitary accommodation from a kitchen



Entry to a bathroom via a corridor or landing



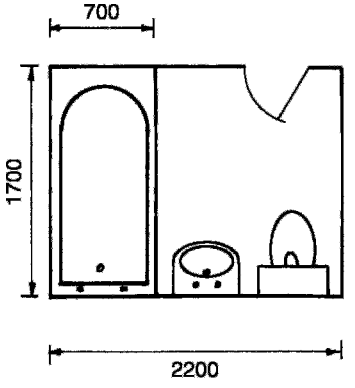
Entry to a bathroom directly from a bedroom

Refs: Building Regulations, Approved Document G – Hygiene.
Building Regulations, Approved Document F – Ventilation. (See Part 5.)

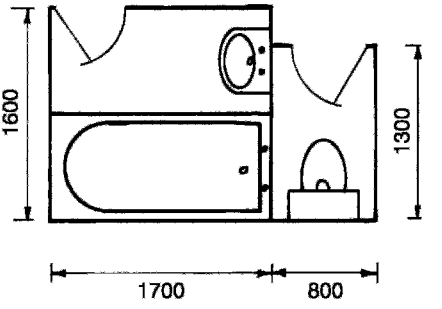
The British Standard recommends that every new dwelling is fitted with at least one WC, one bath or shower, one wash basin and one sink. In dwellings accommodating five or more people there should be two WCs, one of which may be in a bathroom. Any WC compartment not adjoining a bathroom shall also contain a wash basin. Where two or more WCs are provided, it is preferable to site them on different floors.

The number of appliances recommended for non-domestic premises such as offices, factories, shops, etc. varies considerably. BS 6465-1 should be consulted for specific situations.

Bathroom arrangements are detailed in BS 6465-2. Some simple domestic layouts are shown below, with minimum dimensions to suit standard appliances and activity space.



Minimum bathroom requirements

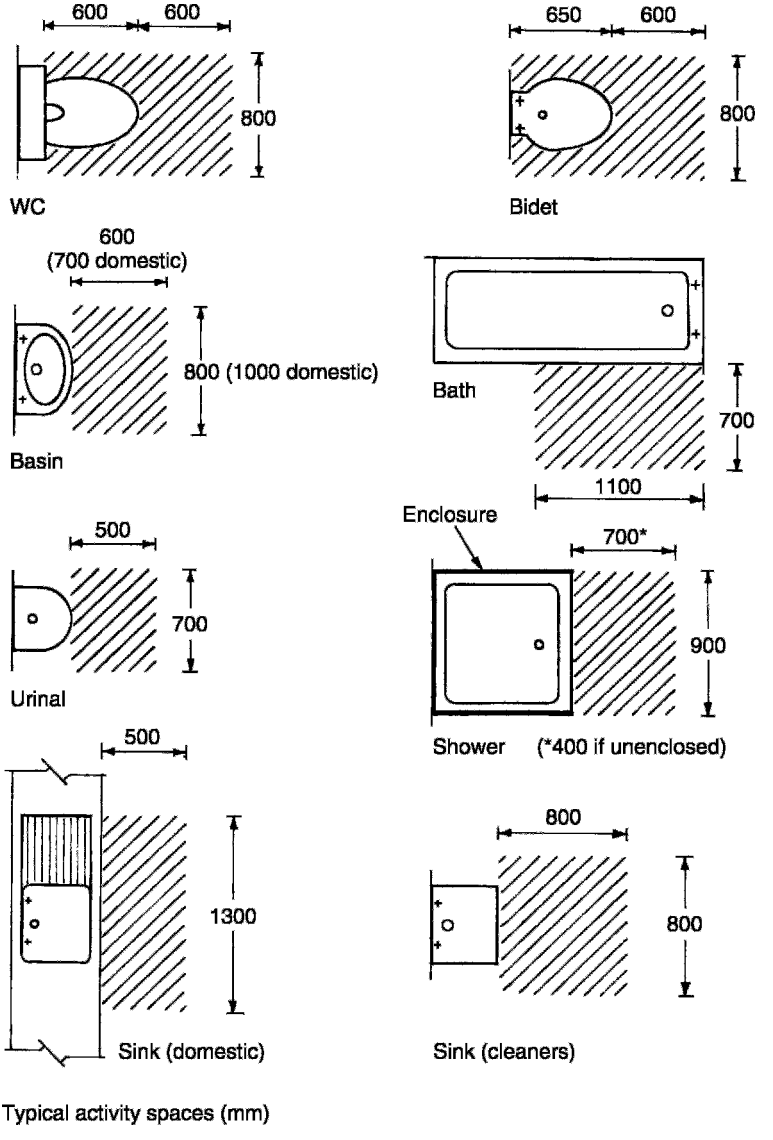


Alternative with adjacent WC compartment

Design of appliances should be such that they are smooth, impervious and manufactured from non-corrosive materials. They should be self-cleansing in operation and easily accessible for manual cleaning. Simplicity in design and a regard to satisfactory appearance are also important criteria.

Refs: BS 6465-1: Sanitary installations. Code of practice for the design of sanitary facilities and scales of provision of sanitary and associated appliances.
BS 6465-2: Sanitary installations. Code of practice for space requirements for sanitary appliances.

Sufficient space for comfort and accessibility should be provided within WC compartments. The following guidance accepts overlap of adjacent activities and door opening:

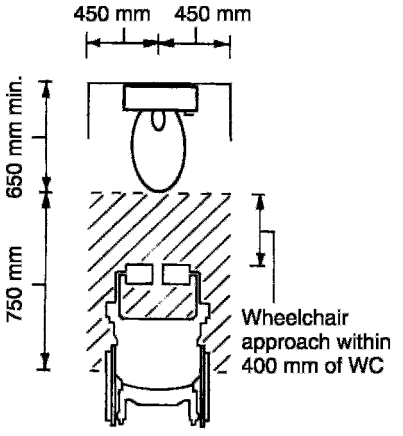


Typical activity spaces (mm)

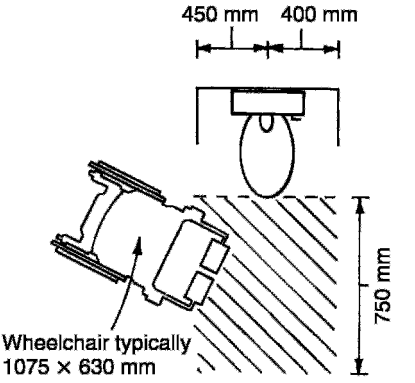
See also the following three pages for spatial and access requirements for disabled persons.

Objectives for WC provision:

- In the entrance storey with unobstructed access.
- Within the principal storey of habitable rooms if this is not at entrance level.
- No higher than the principal storey – stair lift facility to other floors may be considered.
- WC may be located within a bathroom provided that the bath and washbasin are positioned not to impede access.
- Access door opens outwards. Inward opening may be considered if there is clear space for door swing and door can be opened outwards in an emergency.
- Compartment to contain clear space as shown in diagrams.

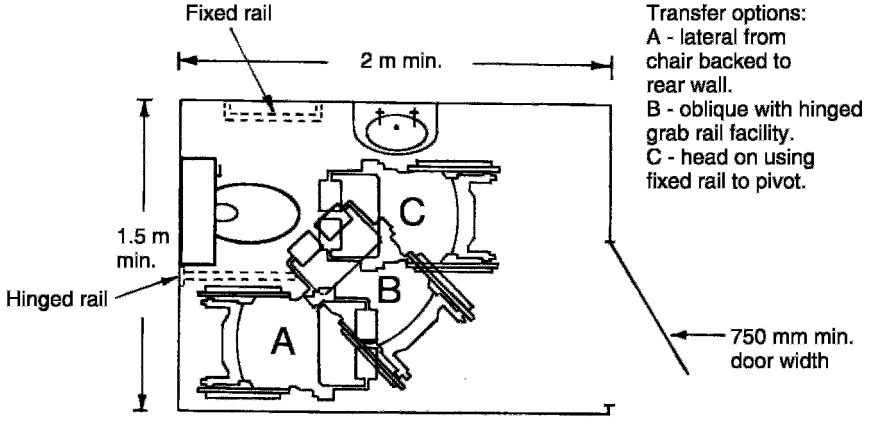


Front access to WC



Oblique access to WC

Minimum clear space allowances



Preferred access to WC

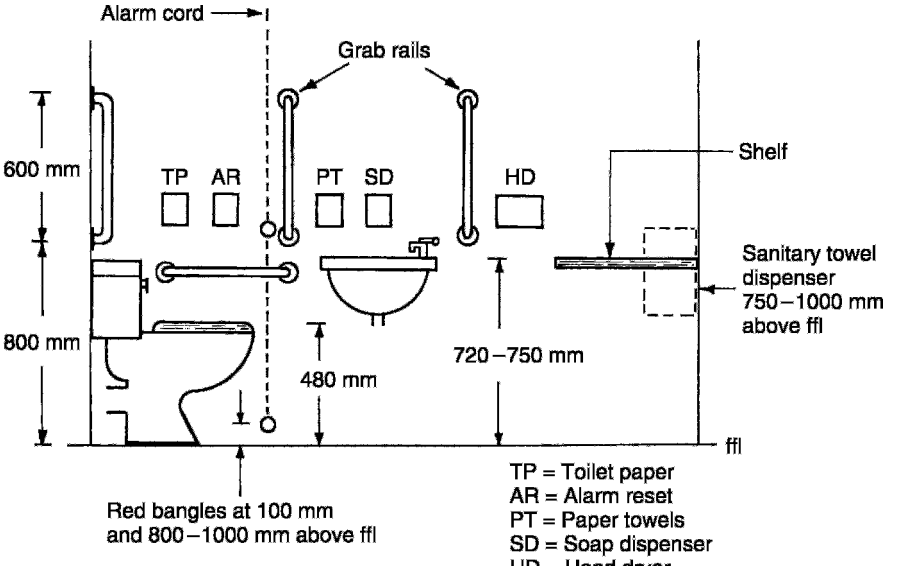
Buildings other than dwellings – at least one unisex WC public lavatory to be provided in cinemas, concert halls, leisure/sports centres, large office buildings, recreational buildings and theatres.

Access dimensions:

Passageway width, minimum 1200 mm.

- Passageway door opening width, minimum 900 mm.
- WC compartment size, minimum 2200 × 1500 mm.
- Door into compartment, minimum 1000 mm clear width.

Note: Compartment door opens outwards. It should have an emergency release device, operated from the outside and a horizontal bar for closing, fitted to the inside.

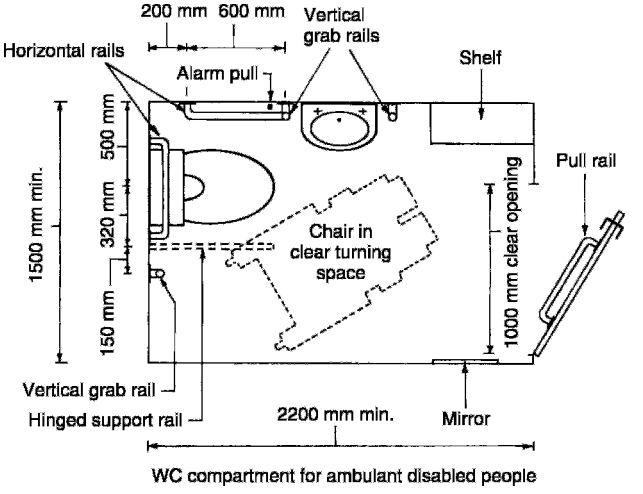


Typical layout of uni-sex WC compartment

Facilities for ambulant (not confined to a wheelchair) disabled people should be provided within conventional separate sex WC and washroom compartments. A suitable compartment will contain some appliances specifically fitted with support rails. There should also be sufficient space to accommodate persons with impaired leg movement and with crutches.

Other provisions and facilities in buildings other than dwellings:

- Support/grab rails of 50 mm minimum diameter, each side of a wash basin.
- Hinged or drop-down rail at least 300 mm long on the exposed side of a WC.
- WC positioned to allow lateral transfer from a wheelchair.
- WC seat of rigid and robust material, set to a height of 480 mm above finished floor level (ffl).
- Means for flushing, maximum 1200 mm above ffl.
- Toilet paper dispenser within easy reach and on the side closest to WC seat.
- Wash basin height maximum 750 mm and reachable whilst seated on WC pan.
- Hand dryer preferred to towels. Unit fitted between 800 and 1000 mm above ffl. Hot air temperature thermostatically set at a maximum of 35°C.
- Wash basin taps of the quarter turn lever type, or an electric sensor operated discharge. Water temperature regulated to 35°C maximum.
- Emergency alarm cord suspended from the ceiling, as close as possible to a wall. Cord fitted with two, 50-mm diameter red bangles set at 100 mm and between 800 and 1000 mm above ffl.



Refs.

Building Regulations, Approved Document M: Access to and use of buildings.

BS 8300: Design of buildings and their approaches to meet the needs of disabled people – Code of Practice.

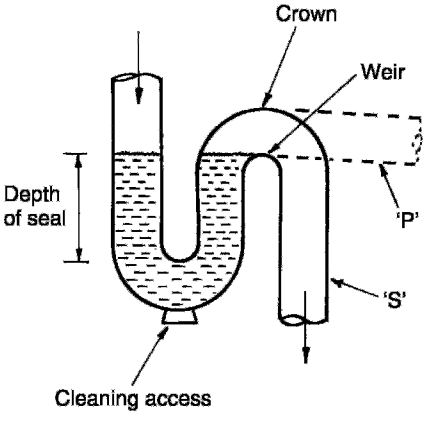
Disability Discrimination Act.

Foul air from the drain and sewer is prevented from penetrating buildings by applying a water trap to all sanitary appliances. A water seal trap is an integral part of gullies and WCs, being moulded in during manufacture. Smaller fittings, i.e. sinks, basins, etc., must be fitted with a trap. The format of a traditional tubular trap follows the outline of the letter 'P' or 'S'. The outlet on a 'P' trap is slightly less than horizontal ($2\frac{1}{2}°$) and on an 'S' trap it is vertical. A 'Q' trap has an outlet inclined at an angle of 45°, i.e. half way between 'P' and 'S'. These are no longer used for sanitation but have an application to gullies.

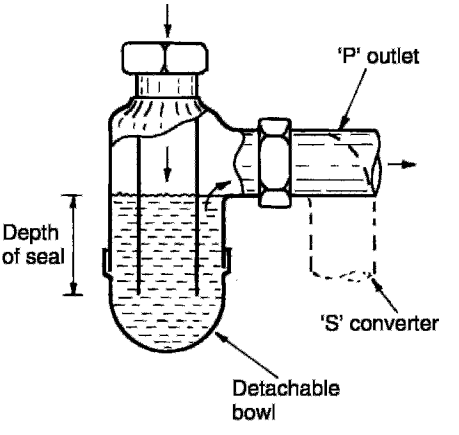
Depth of water seal:

- WCs and gullies – 50 mm (less than smaller fittings as these are unlikely to lose their seal due to the volume of water retained).
- Sanitary appliances other than WCs with waste pipes of 50 mm nominal diameter or less – 75 mm, where the branch pipe connects directly to a discharge stack. However, because of the slow run-off, seal depth may be reduced to 50 mm for baths and shower trays.
- Sinks, baths and showers – 38 mm, where appliance waste pipes discharge over a trapped gully.

Note: Under working and test conditions, the depth of water seal must be retained at not less than 25 mm.



Tubular trap

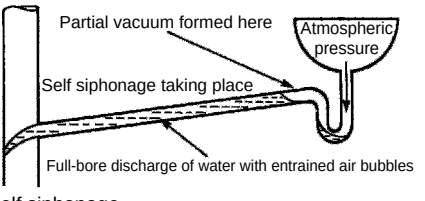


Bottle trap

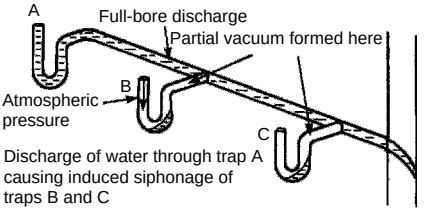
Refs: BS 1184: Copper and copper alloy traps (obsolescent).
BS EN 274: Waste fittings for sanitary appliances.

The most obvious cause of water seal loss is leakage due to defective fittings or poor workmanship. Otherwise, it may be caused by poor system design and/or installation:

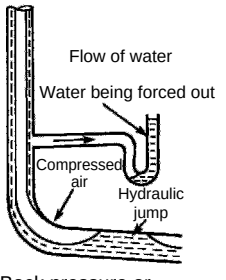
- Self siphonage – as an appliance discharges, the water fills the waste pipe and creates a vacuum to draw out the seal. Causes are a waste pipe that is too long, too steep or too small in diameter.
- Induced siphonage – the discharge from one appliance draws out the seal in the trap of an adjacent appliance by creating a vacuum in that appliance's branch pipe. Causes are the same as for self-siphonage, but most commonly a shared waste pipe that is undersized. Discharge into inadequately sized stacks can have the same effect on waste branch appliances.
- Back pressure – compression occurs due to resistance to flow at the base of a stack. The positive pressure displaces water in the lowest trap. Causes are a too small radius bottom bend, an undersized stack or the lowest branch fitting too close to the base of the stack.
- Capillary action – a piece of rag, string or hair caught on the trap outlet.
- Wavering out – gusts of wind blowing over the top of the stack can cause a partial vacuum to disturb water seals.



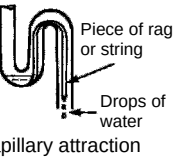
Self siphonage



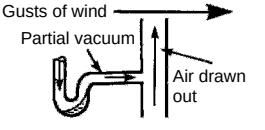
Induced siphonage



Back pressure or compression



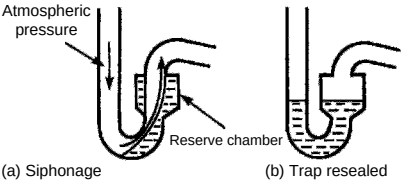
Capillary attraction



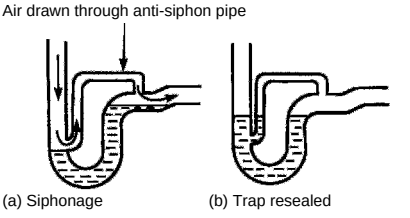
Wavering out

Where trap water seal loss is apparent, the problem may be relieved by fitting either a resealing or an anti-siphon trap. A number of proprietory trap variations are available, some of which include:

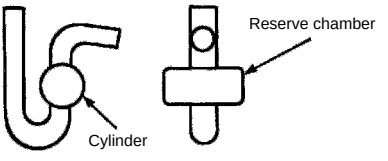
- McAlpine trap – this has a reserve chamber into which water is retained as siphonage occurs. After siphonage, the retained water descends to reseal the trap.
- Grevak trap – contains an anti-siphonage pipe through which air flows to break any siphonic action.
- Econa trap – contains a cylinder on the outlet into which water flows during siphonic action. After siphonage the water in the cylinder replenishes the trap.
- Anti-siphon trap – as siphonage commences, a valve on the outlet crown opens allowing air to enter. This maintains normal pressure during water discharge, preventing loss of water seal.



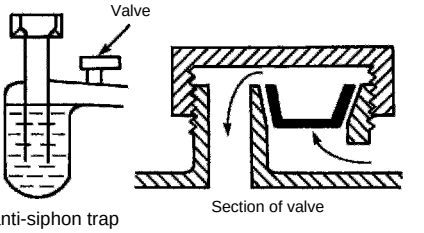
The McAlpine resealing trap



The Grevak resealing trap



The Econa resealing trap

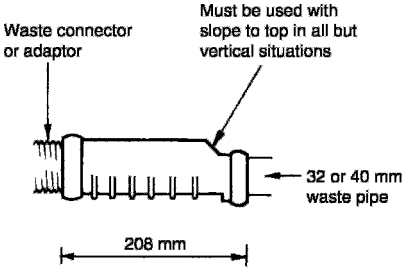


The anti-siphon trap

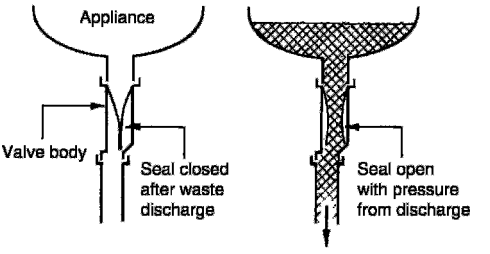
Note: Resealing and anti-siphon traps will require regular maintenance to ensure they are functioning correctly. They can be noisy in use.

Self-Sealing Waste Valve

This compact device has been developed by Hepworth Building Products for use on all sanitary appliances with a 32 or 40 mm nominal diameter outlet. Unlike conventional water seal traps it is a straight section of pipe containing a flexible tubular sealed membrane. This opens with the delivery of waste water and fresh air into the sanitary pipework, resealing or closing after discharge. System design is less constrained, as entry of fresh air into the waste pipework equalises pressures, eliminating the need for traps with air admittance/anti-siphon valves on long waste pipe lengths.



Waste valve



Application

- No siphonage with full-bore discharge.
- Full-bore discharge provides better cleansing of pipework.
- Smaller diameter waste pipes possible as there is no water seal to siphon.
- Anti-siphon and ventilating pipes are not required.
- Ranges of appliances do not need auxiliary venting to stacks.
- No maximum waste pipe lengths or gradients (min. 18 mm/m).
- Space saving, i.e. fits unobtrusively within a basin pedestal.
- Tight radius bends will not affect performance.
- In many situations will provide a saving in materials and installation time.

Note: Manufacturers state compliance with British Standard Codes of Practice and Building Regulations, Approved Documents for drainage and waste disposal.

The single stack system was developed by the Building Research Establishment during the 1960s, as a means of simplifying the extensive pipework previously associated with above ground drainage. The concept is to group appliances around the stack with a separate branch pipe serving each. Branch pipe lengths and falls are constrained. Initially the system was limited to five storeys, but applications have proved successful in high rise buildings of over 20 storeys. Branch vent pipes are not required unless the system is modified. Lengths and falls of waste pipes are carefully selected to prevent loss of trap water seals. Water seals on the waste traps must be 75 mm (50 mm bath and shower).

Branch pipe slope or fall:

Sink and bath – 18 to 90 mm/m

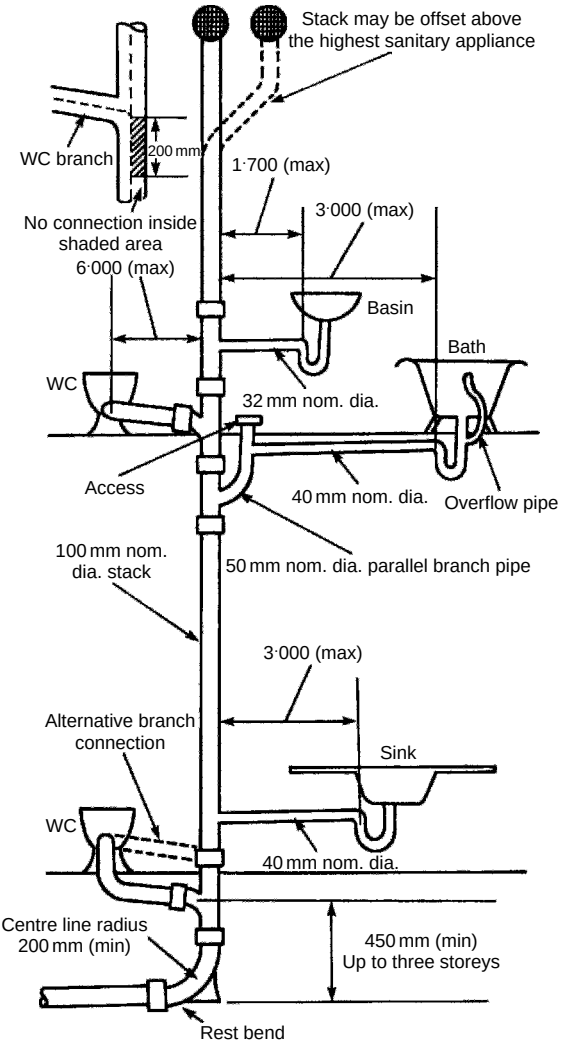
Basin and bidet – 20 to 120 mm/m

WC – 9 mm/m.

The stack should be vertical below the highest sanitary appliance branch. If an offset is unavoidable, there should be no connection within 750 mm of the offset.

The branch bath waste connection must be at least 200 mm below the centre of the WC branch to avoid crossflow. This may require a 50 mm nom. dia. parallel pipe to offset the bath waste pipe, or an 'S' trap WC to offset its connection.

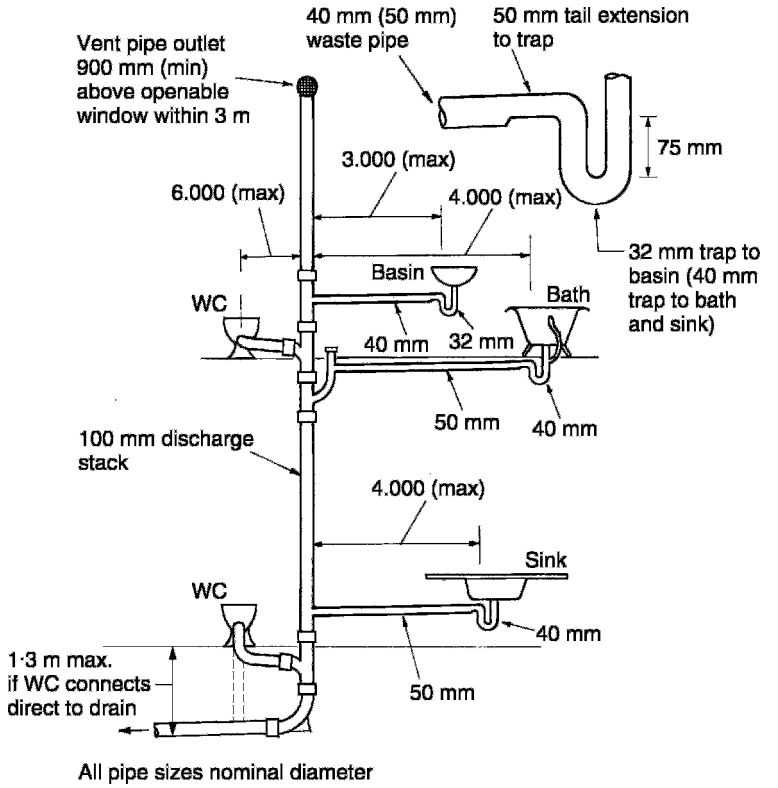
The vent part of the stack may reduce to 75 mm nom. dia. when it is above the highest branch.



Single Stack System – Modified

If it is impractical to satisfy all the requirements for waste pipe branches in a standard single stack system, some modification is permitted in order to maintain an acceptable system performance:

- Appliances may be fitted with resealing or anti-siphon traps (see page 309).
- Branch waste pipes can be ventilated (see pages 314 and 315).
- Larger than standard diameter waste pipes may be fitted.



Note: Where larger than standard branch pipes are used, the trap size remains as standard. Each trap is fitted with a 50 mm tail extension before connecting to a larger waste pipe.

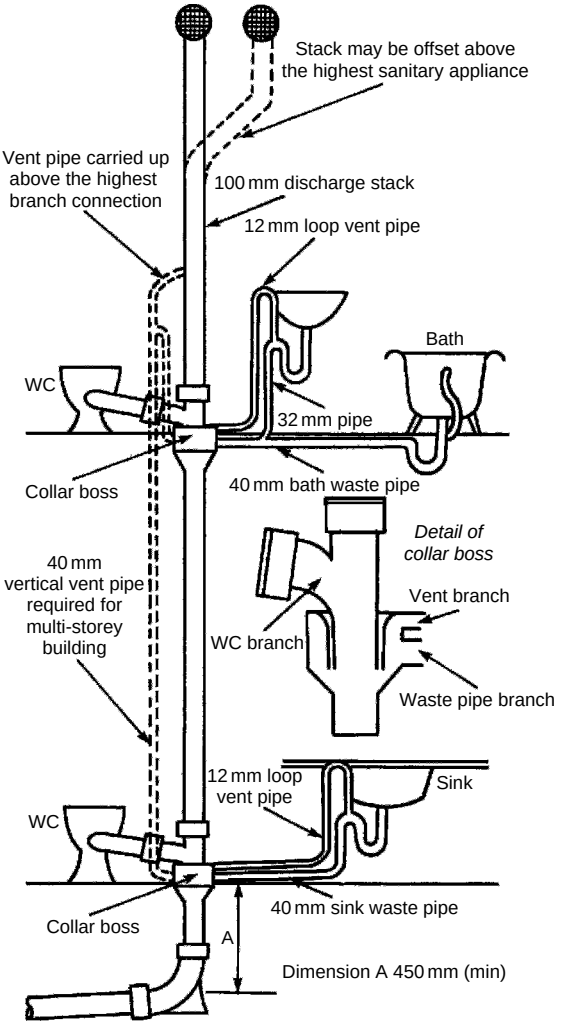
Refs: Building Regulations, Approved Document H1, Section 1: Sanitary pipework.
BS EN 12056: Gravity drainage systems inside buildings (in 6 parts).

The collar boss system is another modification to the standard single stack system. It was developed by the Marley company for use with their uPVC pipe products. The collar is in effect a gallery with purpose-made bosses for connection of waste pipes to the discharge stack without the problem of crossflow interference. This simplifies the bath waste connection and is less structurally disruptive.

Small diameter loop vent pipes on (or close to) the basin and sink traps also connect to the collar. These allow the use of `S´ traps and vertical waste pipes without the possibility of siphonage, even when the bath waste discharges and flows into the combined bath and basin waste pipe. Vertical outlets are also likely to be less obtrusive and less exposed than higher level `P´ trap waste pipes.

If the branch waste pipes are kept to minimal lengths, the loop vents may not be required. However, the system must be shown to perform adequately under test without the loss of trap water seals.

All pipe sizes shown are nominal inside diameter. There may be some slight variation between different product manufacturers, particularly those using outside diameter specifications. Note that there is not always compatibility between different manufacturers´ components.



Modified Single Stack System

The ventilated stack system is used in buildings where close grouping of sanitary appliances occurs – typical of lavatories in commercial premises. The appliances need to be sufficiently close together and limited in number not to be individually vented.

Requirements:

WCs:

8 maximum

100 mm branch pipe

15 m maximum length

Gradient between 9 and 90 mm/m (θ = 90½°–95°).

Basins:

4 maximum

50 mm pipe

4 m maximum length

Gradient between 18 and 45 mm/m (θ = 91°–92½°).

Urinals (bowls):

5 maximum

50 mm pipe

Branch pipe as short as possible

Gradient between 18 and 90 mm/m.

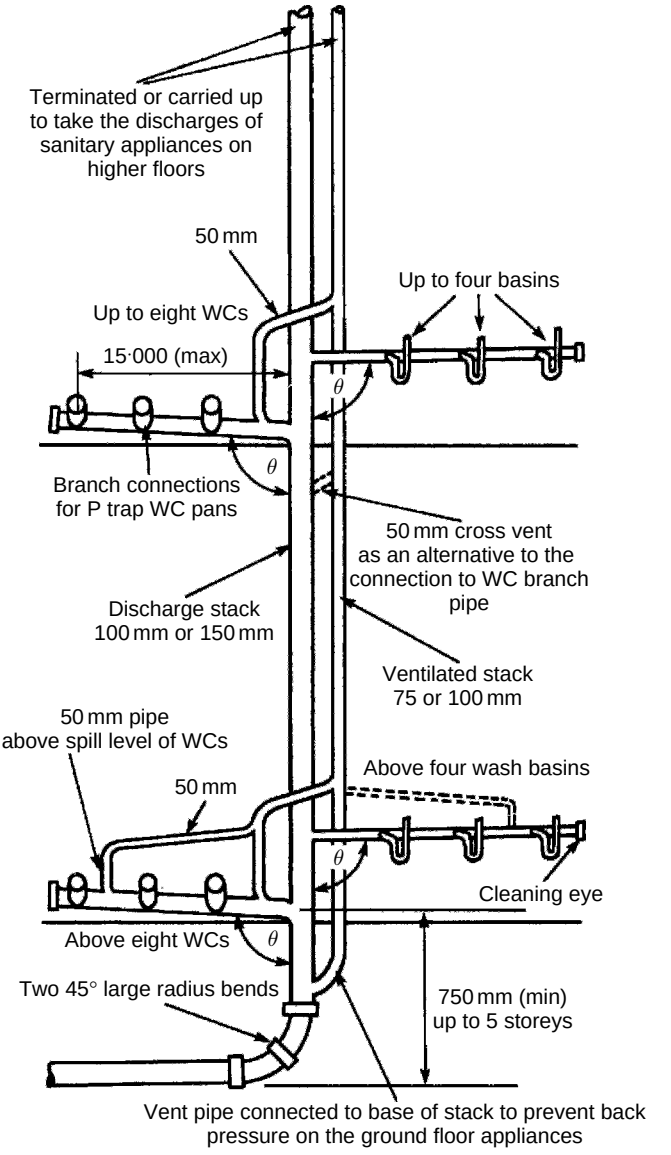
Urinals (stalls):

7 maximum

65 mm pipe

Branch pipe as for bowls.

All pipe sizes are nominal inside diameter.

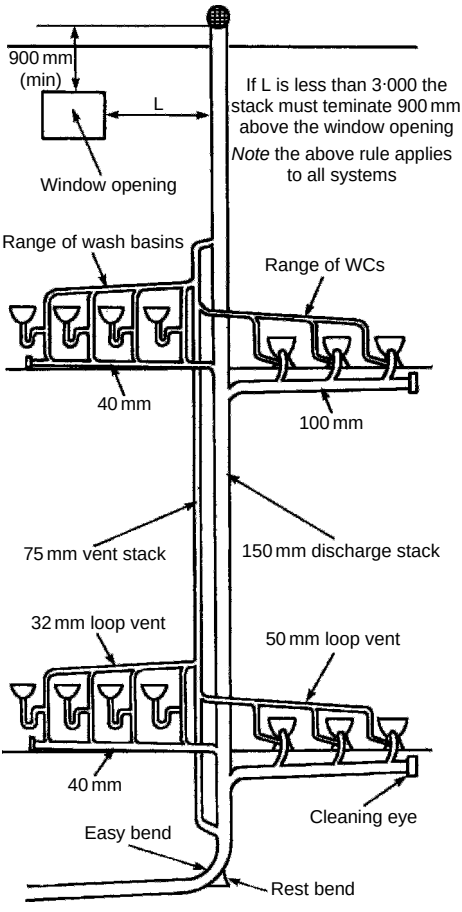


The fully vented one-pipe system is used in buildings where there are a large number of sanitary appliances in ranges, e.g. factories, schools, offices and hospitals.

The trap on each appliance is fitted with an anti-siphon or vent pipe. This must be connected within 300 mm of the crown of the trap.

Individual vent pipes combine in a common vent for the range, which is inclined until it meets the vertical vent stack. This vent stack may be carried to outside air or it may connect to the discharge stack at a point above the spillover level of the highest appliance.

The base of the vent stack should be connected to the discharge stack close to the bottom rest bend to relieve any compression at this point.



Size of branch and stack vents:

Discharge pipe or stack (D) (mm)	Vent pipe (mm)
<75	0·67D
75–100	50
>100	0·50D

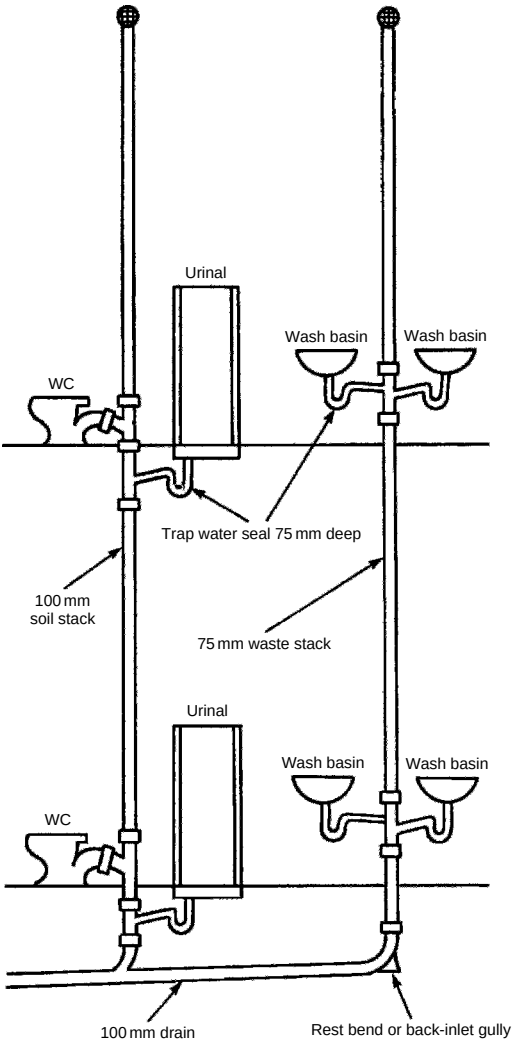
All pipe sizes are nominal inside diameter.

The Two-pipe System

This system was devised to comply with the old London County Council requirements for connection of soil (WC and urinal) and waste (basin, bath, bidet, sink) appliances to separate stacks. For modern systems the terms soil and waste pipes are generally replaced by the preferred terminology, discharge pipes and discharge stacks.

There are many examples of the two-pipe system in use. Although relatively expensive to install, it is still permissible and may be retained in existing buildings that are the subject of refurbishment.

It may also be used where the sanitary appliances are widely spaced or remote and a separate waste stack is the only viable method for connecting these to the drain.

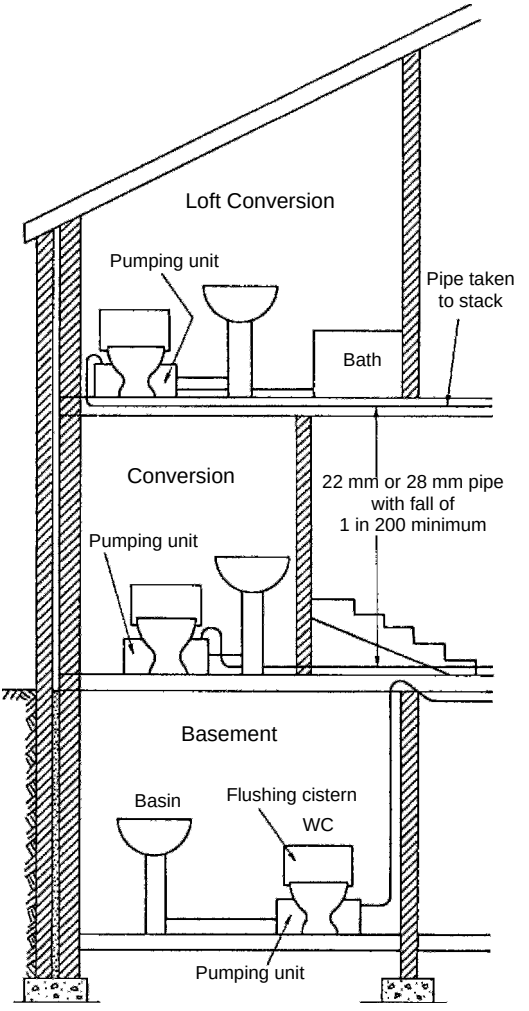


A variation typical of 1930s dwellings has first floor bath and basin wastes discharging through the wall into a hopper. The waste stack from this and the ground floor sink waste discharge over a gully.

A gully may be used as an alternative to a rest bend before the drain.

These systems are particularly useful where sanitary appliance location is impractical, relative to the existing discharge pipework and stack, e.g. loft conversions and basements. The macerator, pump and small diameter discharge pipe are fairly compact, and unlikely to cause structural disruption on the scale of modifications to a conventional gravity flow system.

There are a variety of proprietary pumping systems, most capable of delivering WC and basin discharge over 20 m horizontally and 4 m vertically. Only products that have been tested and approved by the European Organisation for Technical Approvals (EOTA) or their recognised members, e.g. British Board of Agrément (BBA), are acceptable for installation under the Building Regulations.



Installation is at the discretion of the local water and building control authorities. They will not accept the permanent connection of a WC to a macerator and pump, unless there is another WC connected to a gravity discharge system within the same building.

Pipework may be in 22 or 28 mm outside diameter copper tube or equivalent in stainless steel or polypropylene. Easy bends, not elbow fittings must be deployed at changes in direction.

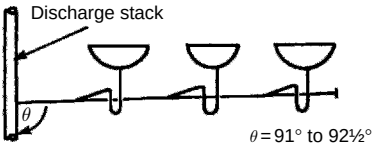
The arrangement of waste and vent pipes for ranges of basins depends upon the type of building and the number of basins in the range. See BS 6465-1: Sanitary installations. Code of practice for scale of provision, selection and installation of sanitary appliances, to determine exact requirements for different purpose groups of building.

For ranges of up to four basins, branch ventilating pipes are not necessary, providing that the inside diameter of the main waste pipe is at least 50 mm and its slope is between 1° and $2\frac{1}{2}$° (18 mm to 45 mm/m).

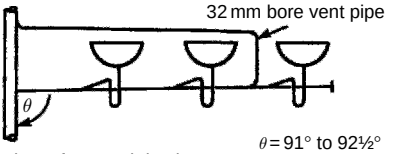
For ranges above four basins, the inside diameter and slope is the same, but a 32 mm nominal inside diameter vent pipe is required. Alternatively, resealing or anti-siphon traps may be used.

In schools and factories a running trap may be used, providing that the length of main waste pipe does not exceed 5 m. Alternatively, the wastes may discharge into a glazed channel with a trapped gully outlet to the stack.

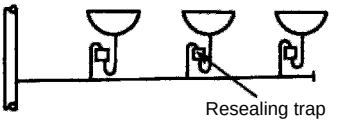
For best quality installation work, all traps may be provided with a vent or anti-siphon pipework.



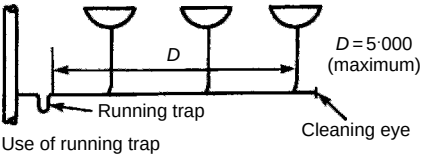
Up to four wash basins



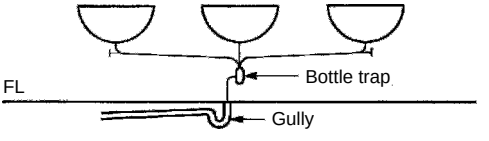
Above four wash basins



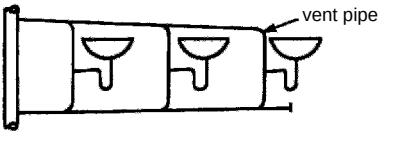
Use of resealing or anti-siphon traps



Use of running trap

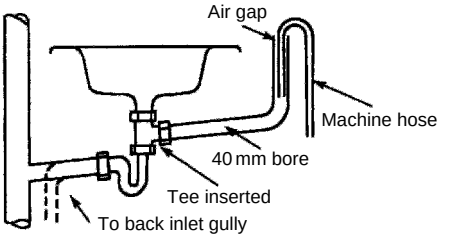


Use of bottle trap

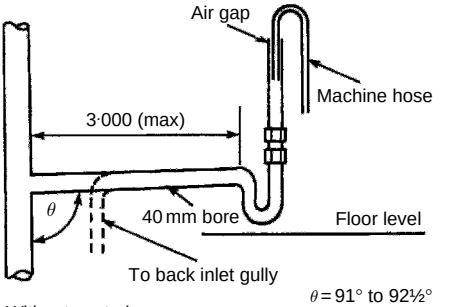


Use of trap ventilating pipes

The simplest method for discharging the hose pipe from a washing machine or dishwasher is to bend the hose pipe over the rim of the sink. However, this is unattractive and may be inconvenient if the hose pipe creates an obstruction. A more discrete and less obtrusive arrangement is to couple the hose to a tee fitting or purpose-made adaptor located between the trap and waste outlet of the sink. If a horizontal waste pipe is required at low level behind kitchen fitments, it must be independently trapped and some provision must be made for the machine outlet to ventilate to atmosphere (a purpose-made vent must not be connected to a ventilating stack). Alternatively, the machine hose pipe may be inserted loosely into the vertical waste pipe leaving an air gap between the two pipes.

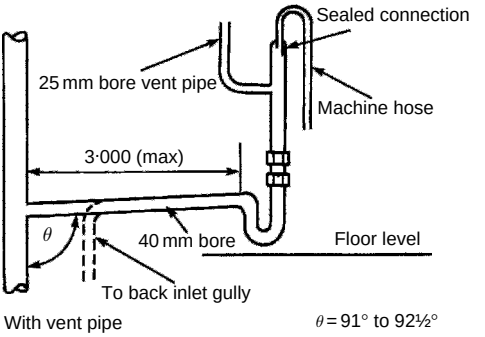


Connection to sink waste pipe



Without vent pipe

$\theta = 91° \text{ to } 92½°$



With vent pipe

$\theta = 91° \text{ to } 92½°$

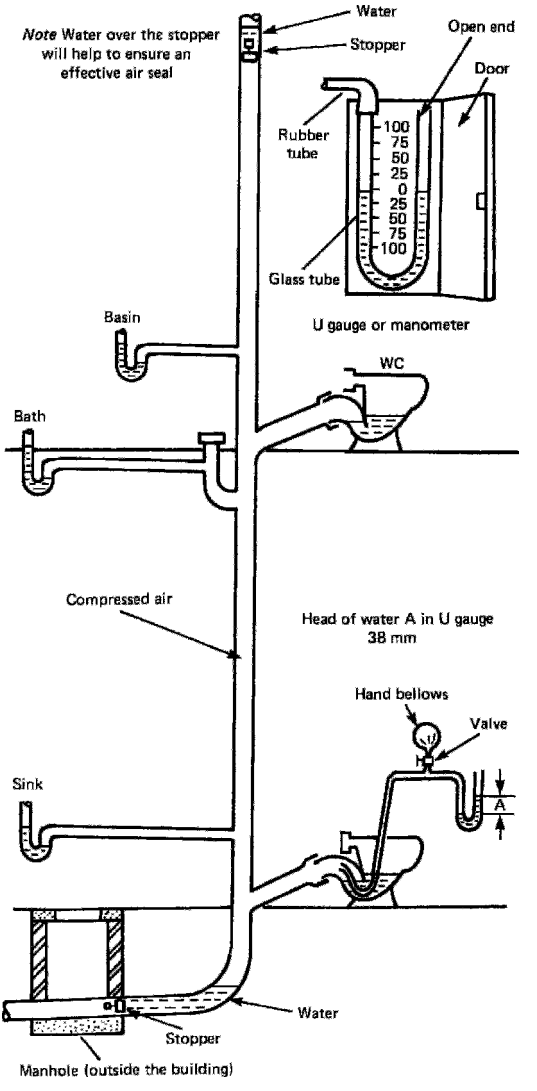
Approved Document H1 to the Building Regulations provides guidance on an acceptable method for determining air tightness of sanitary pipework systems. Installations must be capable of withstanding an air or smoke test pressure at least equal to a 38 mm head of water for a minimum of 3 minutes. Smoke testing is not recommended for use with uPVC pipework.

Equipment for the air test:

Manometer (U gauge), rubber tube, hand bellows and two drain plugs or stoppers.

Procedure:

Stoppers are inserted at the top and bottom of the discharge stack. Each stopper is sealed with water, the lower seal with a flush from a WC. Traps to each appliance are primed to normal depth of seal. The rubber tube connected to the manometer and bellows is passed through the water seal in a WC. Hand bellows are used to pump air into the stack until the manometer shows a 38 mm water displacement. After a few minutes for air temperature stabilisation, the water level in the manometer must remain stationary for 3 minutes. During this time, every trap must maintain at least 25 mm of water seal.



Appliances:

Fitment	Capacity (l)	Discharge flow rate (l/s)
Basin	6	0·6
Basin – spray tap	–	0·06
Bath	80	1·1
Shower	–	0·1
Sink	23	0·9
Urinal	4·5	0·15
Washing machine	180	0·7
Water closet	6	2·3

All appliances in a dwelling are unlikely to be used simultaneously, therefore the flow rate that stacks and drains have to accommodate is not the summation of their respective discharges. Allowing for normal usage, the anticipated flow rates from dwellings contained one WC, one bath, one or two wash basins and one sink are as follows:

Flow rates per dwelling:

No. of dwellings	Flow rate (l/s)
1	2·5
5	3·5
10	4·1
15	4·6
20	5·1
25	5·4
30	5·8

Discharge stack sizes:

Min. stack size (nom. i.d.)	Max. capacity (l/s)
50	1·2
65	2·1
75	3·4
90	5·3
100	7·2

Stacks serving urinals, not less than 50 mm.

Stack serving one or more washdown WCs, not less than 100 mm.

If one siphonic WC with a 75 mm outlet, stack size also 75 mm.

Discharge pipe and trap sizes:

Fitment	Trap and pipe nom. i.d. (mm)	Trap water seal (mm)
Basin	32	75
Bidet	32	75
Bath	40	75*
Shower	40	75*
Sink	40	75*
Dishwasher	40	75
Washing machine	40	75
Domestic food waste disposal unit	40	75
Commercial food waste disposal unit	50	75
Urinal bowl	40	75
Urinal bowls (2–5)	50	75
Urinal stalls (1–7)	65	50
WC pan – siphonic	75	50‡
WC pan – washdown	100†	50‡
Slop hopper	100†	50‡

* 38 mm if discharging to a gully.
† Nominally 100 mm but approx. 90 mm (min. 75 mm).
‡ Trap integral with fitment.

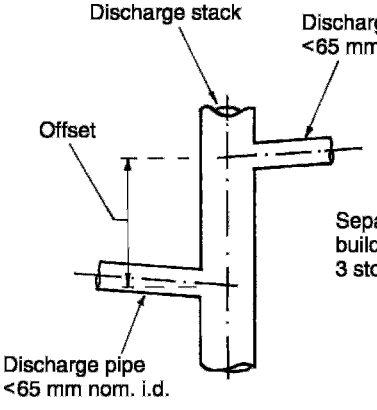
Bath and shower trays may be fitted with 50 mm seal traps.
The following materials are acceptable for sanitary pipework:

Application	Material	Standard
Discharge pipes and stacks	Cast iron	BS 416-1 and BS EN 877
	Copper	BS EN's 1254 and 1057
	Galv. steel	BS 3868
	uPVC	BS EN 1329-1
	Polyethylene	BS 1519-1
	Polypropylene	BS EN 1451-1
	MuPVC	BS 5255
	ABS	BS EN 1455-1
Traps	Copper	BS 1184 (obsolescent)
	Polypropylene	BS EN 274

Offsets have two interpretations:

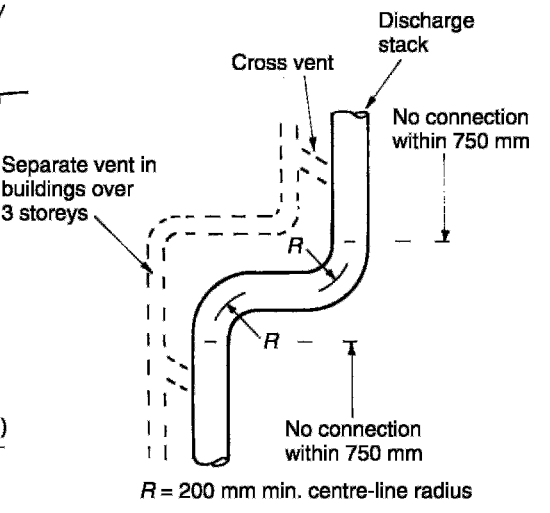
1. Branch waste or discharge pipe connections to the discharge stack. Typically the 200 mm offset required for opposing bath and WC discharge pipes – see page 311. Additional requirements are shown below.

2. Stack offsets – to be avoided, but may be necessary due to the structural outline of the building to which the stack is attached. Large radius bends should be used and no branch connections are permitted within 750 mm of the offset in buildings up to three storeys. In buildings over three storeys a separate vent stack may be needed. This is cross-vented to the discharge stack above and below the offset to relieve pressure. Bends and offsets are acceptable above the highest spillover level of an appliance. They are usually necessary where external stacks avoid eaves projections.



Offset (mm)	Stack nom. i.d. (mm)
110	100
250	150

Discharge pipes offset



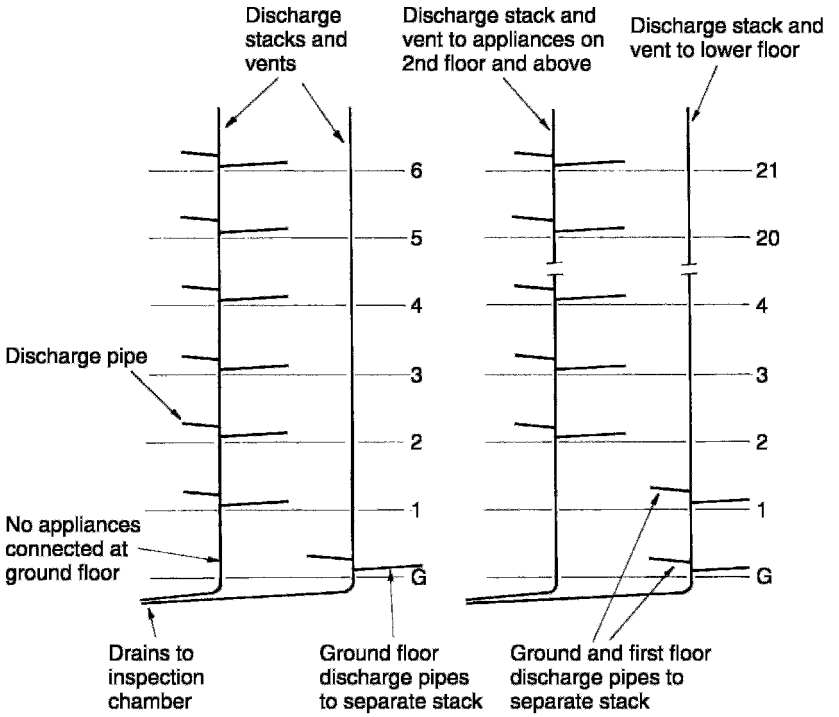
Stack offset

Note: Discharge stacks may be located internally or externally to buildings up to three storeys. Above three storeys, stacks should be located internally.

Lowest discharge pipe connection to stack:

Up to three storeys – 450 mm min. from stack base (page 311).
Up to five storeys – 750 mm min. from stack base (page 314).

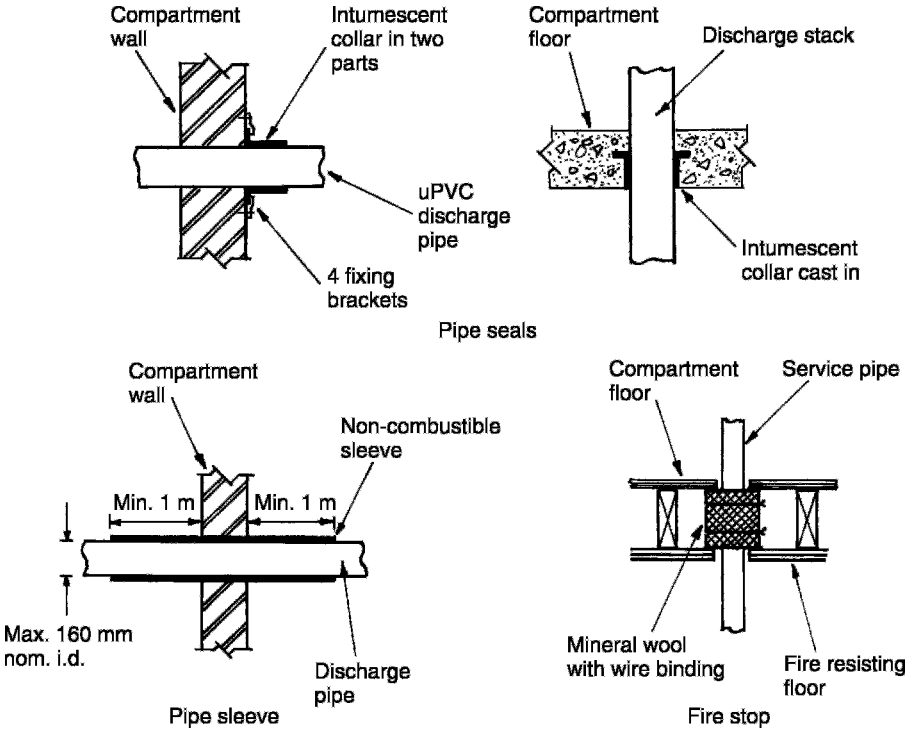
Above five storeys, the ground floor appliances should not connect into the common stack, as pressure fluctuations at the stack base could disturb the lower appliance trap water seals. Above 20 storeys, both ground and first floor appliances should not connect into the common stack. Ground and first floor appliances so affected can connect directly to a drain or gully, or be provided with a stack specifically for lower level use.



Access – required for clearing blockages. Rodding points should be fitted at the end of discharge pipes, unless trap removal provides access to the full pipe length. Discharge stacks are accessed from the top and through access plates located midway between floors at a maximum spacing of three storeys apart.

For fire protection and containment purposes, the Building Regulations divide parts or units within buildings into compartments. A typical example is division of a building into individual living units, e.g. flats. The dividing compartment walls and floors have fire resistances specified in accordance with the building size and function.

Where pipes penetrate a compartment interface, they must have a means of preventing the spread of fire, smoke and hot gases through the void they occupy. Non-combustible pipe materials may be acceptably sealed with cement and sand mortar, but the most vulnerable are plastic pipes of low heat resistance. The void through which they pass can be sleeved in a non-combustible material for at least 1 m each side. One of the most successful methods for plastic pipes is to fit an intumescent collar at the abutment with, or within, the compartment wall or floor. Under heat, these become a carbonaceous char, expand and compress the warm plastic to close the void for up to four hours.



Ref: Building Regulations, Approved Document B3: Internal fire spread (structure).

Note: See also page 520.

Simultaneous demand process – considers the number of appliances likely to be used at any one time, relative to the total number installed on a discharge stack.

Formula:

$$m = np + 1{\cdot}8\ \sqrt{2np(1-p)}$$

where: m = no of appliances discharging simultaneously
n = no. of appliances installed on the stack
p = appliance discharge time (t) ÷ intervals between use (T).

Average time for an appliance to discharge = 10 seconds (t)
Intervals between use (commercial premises) = 600 seconds (T)
(public premises) = 300 seconds (T)

Commercial premises, e.g. offices, factories, etc., p = 10 ÷ 600 = 0·017.
Public premises, e.g. cinemas, stadium, etc., p = 10 ÷ 300 = 0·033.

E.g. an office building of ten floors with four WCs, four urinals, four basins and one sink on each floor.

Total number of appliances (n) = 13 × 10 floors = 130

Substituting factors for p and n in the formula:

$$m = (130 \times 0{\cdot}017) + 1{\cdot}8\sqrt{2 \times 130 \times 0{\cdot}017\,(1 - 0{\cdot}017)}$$
$$m = 2{\cdot}21 + (1{\cdot}8 \times 2{\cdot}08) = 5{\cdot}96$$

Simultaneous demand factor = m ÷ n
= 5·96 ÷ 130 = 0·045 or 4·5%

Flow rates (see page 321):

Four WCs at 2·3 l/s	=	9·2
Four urinals at 0·15 l/s	=	0·6
Four basins at 0·6 l/s	=	2·4
One sink at 0·9 l/s	=	0·9
Total per floor	=	13·1 l/s
Total for ten floors	=	131 l/s

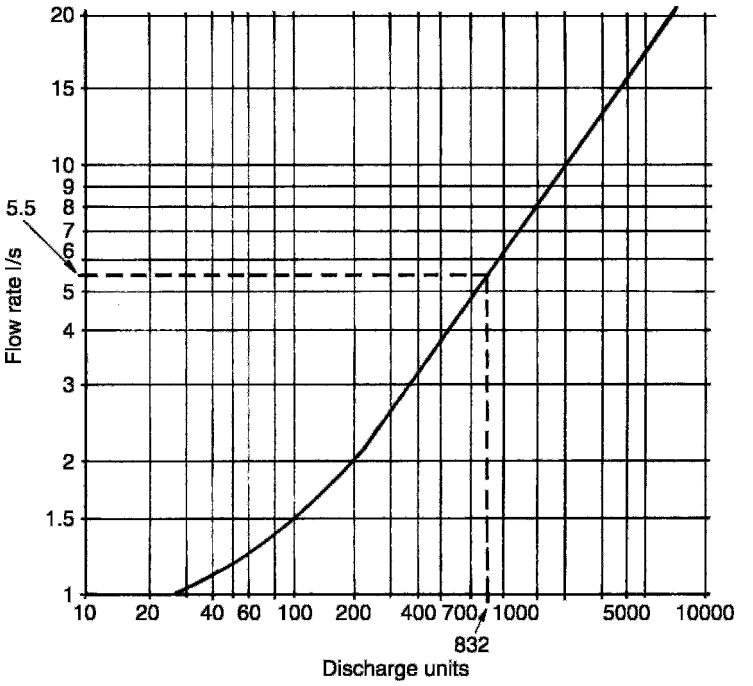
Allowing 4·5% simultaneous demand = 131 × 4·5% = 5·9 l/s.

The use of discharge units for drain and sewer design is shown on pages 267 and 268. The same data can be used to ascertain the size of discharge stacks and pipes.

Using the example from the previous page:

Four WCs at 14 DUs	= 56
Four urinals at 0·3 DUs	= 1·2
Four basins at 3 DUs	= 12
One sink at 14 DUs	= 14
Total per floor	= 83·2
Total for ten floors	= 832 discharge units

Discharge units can be converted to flow in litres per second from the chart:



From the chart, a total loading of 832 discharge units can be seen to approximate to 5·5 l/s. A fair comparison with the 5·9 l/s calculated by formula on the preceding page.

Formula:

$$q = K \sqrt[3]{d^8}$$

where: q = discharge or flow rate in l/s
K = constant of 32×10^{-6}
d = diameter of stack in mm.

Transposing the formula to make d the subject:

$$d = \sqrt[8]{(q \div K)^3} \qquad q = 5{\cdot}5 \text{ l/s (see previous page)}$$

$$d = \sqrt[8]{(5{\cdot}5 \div 32 \times 10^{-6})^3}$$

$$= 91{\cdot}9 \text{ mm, i.e. a 100 mm nom. i.d. stack.}$$

Discharge units on stacks:

Discharge stack nom. i.d. (mm)	Max. No. of DUs
50	20
65	80
75	200
90	400
100	850
150	6400

Using the example from the preceding page, 832 discharge units can be adequately served by a 100 mm diameter stack.

Discharge units on discharge branch pipes:

Discharge pipe, nom. i.d. (mm)	Branch gradient		
	1 in 100	1 in 50	1 in 25
32		1	1
40		2	8
50		10	26
65		35	95
75	40	100	230
90	120	230	460
100	230	430	1050
150	2000	3500	7500

Ref: BS EN 12056-2: Gravity drainage systems inside buildings. Sanitary pipework, layout and calculation.

The discharge unit method of stack and drain design shown on the preceding pages has limitations where a building or group of buildings are of mixed occupancy. For example, a hotel containing bedrooms, offices, commercial kitchens, etc. In these situations there are different frequencies of appliance use.

The 'K' factor method is very adaptable. It uses a peak design flow coefficient. This allows for frequency of appliance use, applied to the total possible disposal from all stack or drain connected appliances.

Comparison with discharge units (see page 267):

Application	Discharge unit time interval (min)	'K' factor coefficient
Domestic	20	0·5
Commercial	10	0·7
Peak/public/congested	5	1·0

Example based on a mixed occupancy application to a single building, containing 60 private apartments and offices:

Each apartment:

Appliances	Disposal based on flow (see page 321)
2 WCs	4·6 (2 × 2·3)
1 sink	0·9
2 basins	1·2 (2 × 0·6)
1 shower	0·1
1 bath	1·1
1 washing machine	0·7
1 dishwasher	0·2
	8·8 × 60 apartments = 528

Offices:

Appliances		Disposal based on flow (see page 321)
Gents:	4 WCs	9·2 (4 × 2·3)
	8 urinals	1·2 (8 × 0·15)
	6 basins	3·6 (6 × 0·6)
Ladies:	10 WCs	23·0 (10 × 2·3)
	10 basins	6·0 (10 × 0·6)
Kitchen:	2 sinks	1·8 (2 × 0·9)
		44·8

'K' factors: Apartments (domestic) = 0·5 Offices (commercial) = 0·7

To allow for intermittent use of appliances, the following design formula is applied to calculate flow (Q) in litres/second:

$$Q = K \sqrt{\Sigma \text{ disposal}}$$

(continues)

Before calculating the flow, an adjustment is needed to the lesser figure to represent its proportional disposal. This is achieved by applying a conversion factor from the lesser to the greater flow:

Lesser flow	Greater flow	'K' conversion factor
Domestic	Commercial	0·5 ÷ 0·7 = 0·714
Domestic	Peak/public/congested	0·5 ÷ 1·0 = 0·5
Commercial	Domestic	0·7 ÷ 0·5 = 1·4
Commercial	Peak/public/congested	0·7 ÷ 1·0 = 0·7
Peak/public/congested	Domestic	1·0 ÷ 0·5 = 2·0
Peak/public/congested	Commercial	1·0 ÷ 0·7 = 1·428

In this example the lesser disposal is from the offices, i.e. 44·8. The commercial – domestic converter is 1.4, therefore $44{\cdot}8 \times 1{\cdot}4 = 62{\cdot}72$. Adding this to the greater domestic disposal of 528, gives a total of 590·72.

Formula application using the 'K' factor for the greater disposal:

$$Q = 0{\cdot}5\sqrt{590{\cdot}72} = 12{\cdot}15 \text{ l/s}$$

Stack design formula from page 328. Taking Q = q.

$$q = K\sqrt[3]{d^8} \quad \text{or} \quad \sqrt[8]{(q \div K)^3}$$

Note: Do not confuse K in the formula with 'K' factor. K in the formula is a constant of 32×10^{-6}.

Therefore, $d = \sqrt[8]{(12{\cdot}15 \div 32 \times 10^{-6})} = 124$ mm, i.e. 150 mm nom. dia. stack.

Drain design formula from page 266. $Q = V \times A$

Where: $Q = 0{\cdot}012$ m^3/s (12.15 l/s) at a modest velocity (V) of 0·8 m/s.

A = Area of flow in drain (use half full bore).

$A = Q \div V = 0{\cdot}012 \div 0{\cdot}8 = 0{\cdot}015$ m^2 (half bore)

Total area of drain pipe = $2 \times 0{\cdot}015 = 0{\cdot}030$ m^2

Pipe area = πr^2 or $r = \sqrt{\text{Pipe area} \div \pi}$ (r = radius)

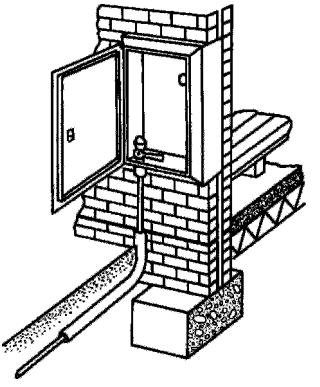
$$r = \sqrt{0{\cdot}030 \div 3{\cdot}142} = 0{\cdot}098 \text{ m}$$

Pipe diameter = 2 × r = 0·196 m or 196 mm

Nearest available standard drain pipe above 196 mm is 225 mm.

Refs: BS EN 12056-2: Gravity drainage systems inside buildings.
BS EN 752: Drain and sewer systems outside buildings.

9 GAS INSTALLATION, COMPONENTS AND CONTROLS



NATURAL GAS – COMBUSTION
MAINS GAS SUPPLY AND INSTALLATION
GAS SERVICE PIPE INTAKE
METERS
GAS CONTROLS AND SAFETY FEATURES
GAS IGNITION DEVICES AND BURNERS
PURGING AND TESTING
GAS APPLIANCES
BALANCED FLUE APPLIANCES
OPEN FLUE APPLIANCES
FLUE BLOCKS
FLUE TERMINALS
FLUE LINING
SHARED FLUES
FAN ASSISTED GAS FLUES
VENTILATION REQUIREMENTS
FLUE GAS ANALYSIS
GAS CONSUMPTION
GAS PIPE SIZING

Properties of natural gas are considered on page 152. Some further features include:

- Ignition temperature, 700°C.
- Stoichiometric mixture – the quantity of air required to achieve complete combustion of gas. For combustion, the ratio of air volume to natural gas volume is about 10·6:1. Therefore, about 10% gas to air mixture is required to achieve complete combustion. As air contains about 20% oxygen, the ratio of oxygen to gas is approximately 2:1. Developing this a little further – natural gas is about 90% methane, therefore:

$$CH_4 + 2O_2 = CO_2 + 2H_2O$$

1 part methane + 2 parts oxygen = 1 part carbon dioxide + 2 parts water

If there is insufficient air supply to a gas burner, incomplete combustion will result. This produces an excess of carbon monoxide in the flue; a toxic and potentially deadly gas.

- Products of complete combustion – water vapour, carbon dioxide and the nitrogen already contained in the air. Correct combustion can be measured by simple tests to determine the percentage of carbon dioxide in flue gases. The Draeger and Fyrite analysers shown on page 372 are suitable means for this assessment.
- Flues – these are necessary to discharge the products of combustion safely and to enhance the combustion process. The application of flues is considered in more detail later in this chapter. Flue size is normally to the boiler manufacturer's recommendations. The principles for determining the correct flue area and length, with regard to efficient fuel combustion and avoidance of condensation in the flue, are provided on pages 376 to 378. Some gas appliances such as small water heaters and cookers are flueless. Provided they are correctly installed, they will produce no ill-effects to users. The room in which they are installed must be adequately ventilated, otherwise the room air could become vitiated (oxygen depleted). For a gas cooker, this means an openable window or ventilator. A room of less than 10 m^3 requires a permanent vent of 5000 mm^2.

BG Group Plc (formerly British Gas Plc) supply gas to communities through a network of mains, installed and maintained by Lattice Group plc (Transco). Gas marketing and after-sales services are provided by a number of commercial franchisees for the consumer's choice.

Some of the underground service pipes have been in place for a considerable time. These are manufactured from steel and although protected with bitumen, PVC or grease tape (Denso), they are being progressively replaced with non-corrosive yellow uPVC for mains and polyethylene for the branch supplies to buildings. The colour coding provides for recognition and to avoid confusion with other utilities in future excavation work.

Mains gas pressure is low compared with mains water. It is unlikely to exceed 75 mbar (750 mm water gauge or 7·5 kPa) and this is reduced by a pre-set pressure governor at the consumer's meter to about 20 mbar.

A service pipe of 25 mm nominal bore is sufficient for normal domestic installations. For multi-installations such as a block of flats, the following can be used as a guide:

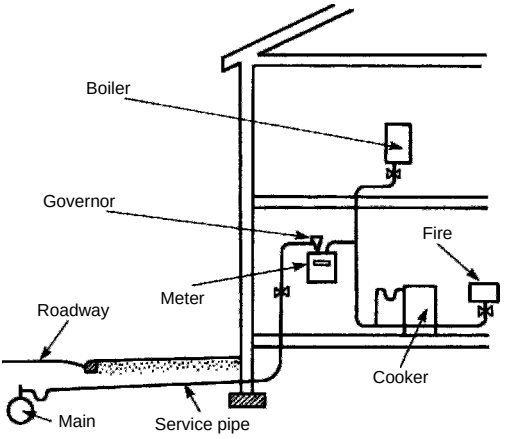
Nominal bore (mm)	No. of flats
32	2–3
38	4–6
50*	>6

* Note: Supplies of 50 mm nom. bore may be provided with a service valve after the junction with the main. Where commercial premises are supplied and the risk of fire is greater than normal, e.g. a garage, a service pipe valve will be provided regardless of the pipe size and its location will be clearly indicated. Pipes in excess of 50 mm nom. bore have a valve fitted as standard.

Gas mains should be protected by at least 375 mm ground cover (450 mm in public areas).

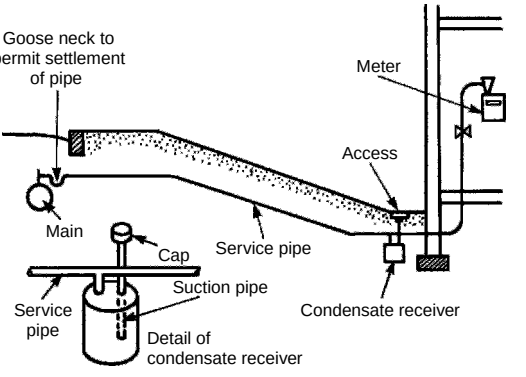
Refs: The Gas Act.
The Gas Safety (Installation and Use) Regulations.

The details shown below represent two different established installations. Some of these may still be found, but unless there are exceptional circumstances, the meter is no longer located within a building. An exception may be a communal lobby to offices or a block of flats. The preferred meter location for the convenience of meter readers and security of building occupants is on the outside of a building. This can be in a plastic cupboard housing on the external wall or in a plastic box with hinged lid sunken into the ground at the building periphery.



Typical house installation

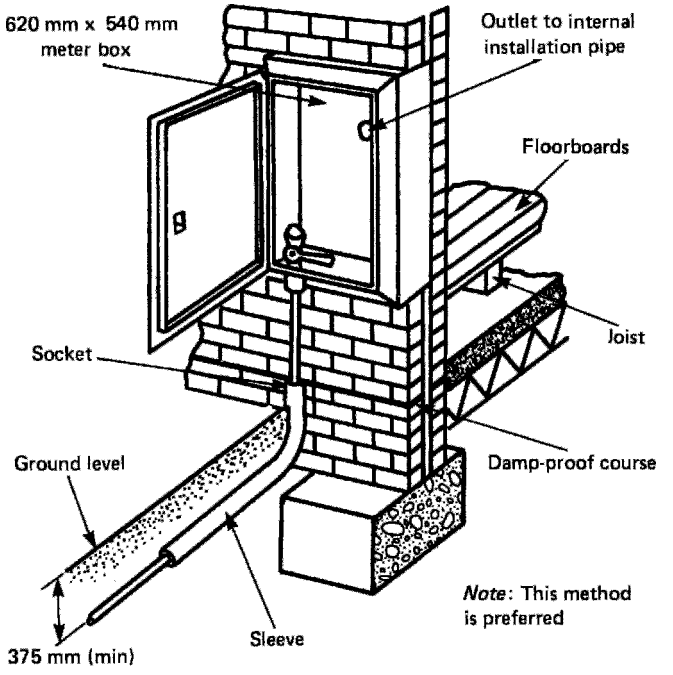
Prior to conversion to natural gas in the 1960s, a condensate receiver was used to trap moisture from town or coal gas where it was impractical to incline the service pipe back to the main.



Use of condensate receiver

A service pipe is the term given to the pipe between the gas main and the primary meter control. A polyethylene pipe is used underground and steel or copper pipe where it is exposed. Wherever possible, the service pipe should enter the building on the side facing the gas main. This is to simplify excavations and to avoid the pipe having to pass through parts of the substructure which could be subject to settlement. The service pipe must not:

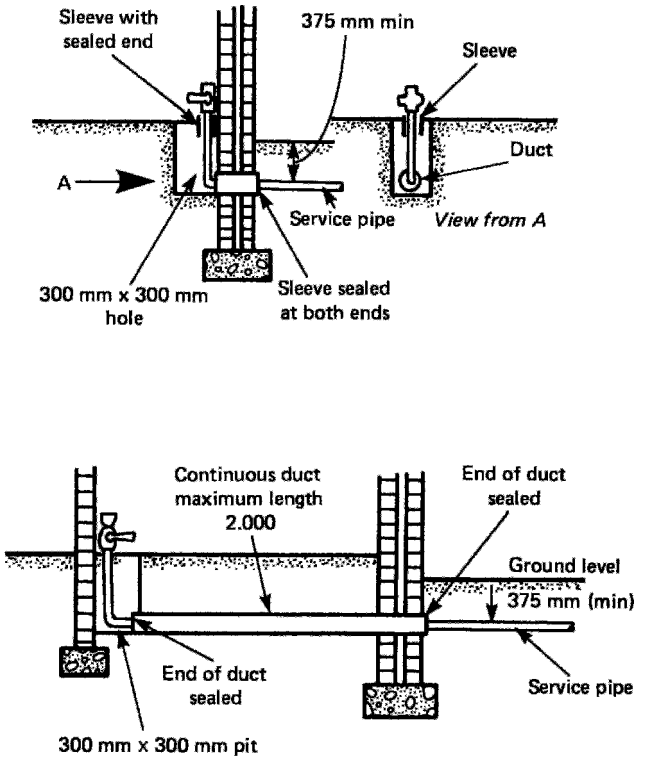
- pass under the base of a wall or foundations to a building
- be installed within a wall cavity or pass through it except by the shortest possible route
- be installed in an unventilated void space – suspended and raised floors with cross-ventilation may be an exception
- have electrical cables taped to it
- be near any heat source.



Entry to an external meter box

Where there is insufficient space or construction difficulties preclude the use of an external meter box or external riser, with certain provisions, the service pipe may be installed under a solid concrete floor or through a suspended floor.

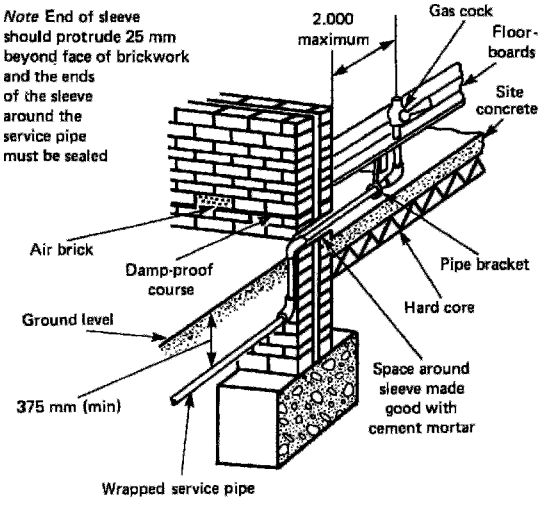
For a solid floor, a sleeve or duct should be provided and built into the wall to extend to a pit of approximately 300 × 300 mm plan dimensions. The service pipe is passed through the duct, into the pit and terminated at the meter position with a control valve. The duct should be as short as possible, preferably not more than 2 m. The space between the duct and the service pipe is sealed at both ends with mastic and the pit filled with sand. The floor surface is made good to match the floor finish. If the floor is exposed concrete, e.g. a garage, then the duct will have to bend with the service pipe to terminate at floor level and be mastic sealed at this point.



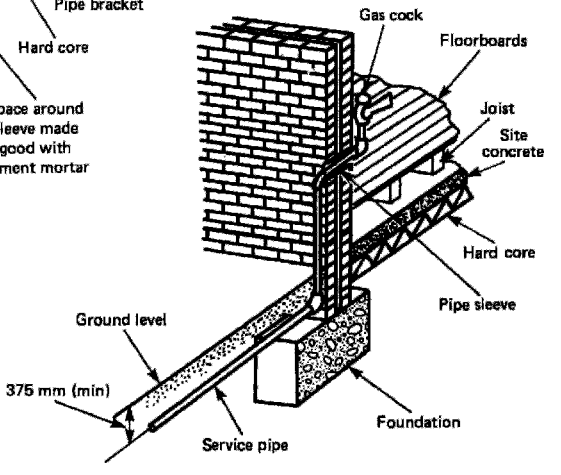
Service pipe entry into solid floor

Where a service pipe passes through a wall or a solid concrete floor, it must be enclosed by a sleeve of slightly larger diameter pipe to provide space to accommodate any building settlement or differential movement. The outside of the sleeve should be sealed with cement mortar and the space between the sleeve and service pipe provided with an intumescent (fire resistant) mastic sealant.

If an internal meter is used, the space or compartment allocated for its installation must be well ventilated. A purpose-made void or air brick to the outside air is adequate. The surrounding construction should be of at least 30 minutes' fire resistance. In commercial and public buildings the period of fire resistance will depend on the building size and purpose grouping.



Service pipe entry into hollow floor



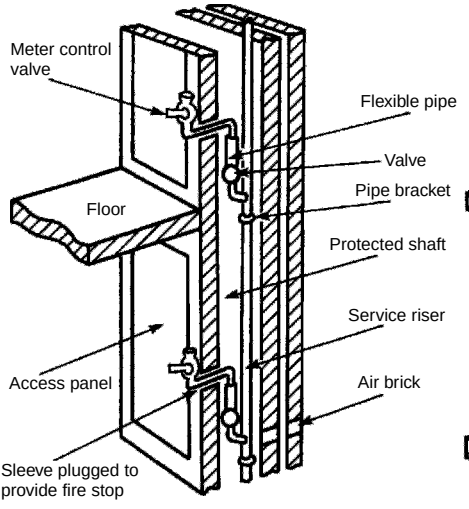
Entry above ground level

Ref: Building Regulations, Approved Document B: Fire safety.

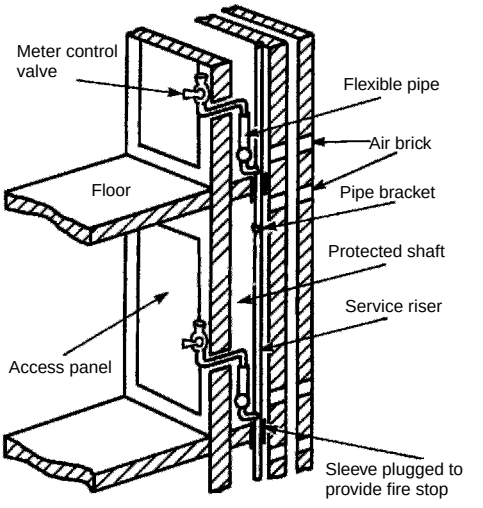
Gas service pipe risers must be installed in fire protected shafts constructed in accordance with the Building Regulations, Approved Document B: Fire safety. Possible methods for constructing a shaft include:

- A continuous shaft ventilated to the outside at top and bottom. In this situation a fire protected sleeve is required where a horizontal pipe passes through the shaft wall.
- A shaft which is fire stopped at each floor level. Ventilation to the outside air is required at both high and low levels in each isolated section.

Shafts are required to have a minimum fire resistance of 60 minutes and the access door or panel a minimum fire resistance of 30 minutes. The gas riser pipe must be of screwed or welded steel and be well supported throughout with a purpose-made plate at its base. Movement joints or flexible pipes and a service valve are provided at each branch.



Service pipe in a continuous shaft

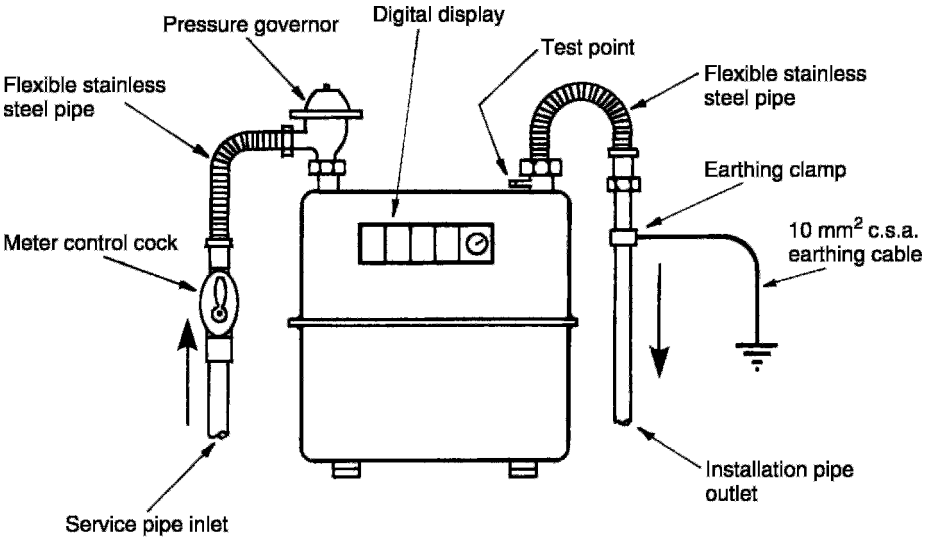


Service pipe in a sectional shaft

Refs: Building Regulations, Approved Document B3: Section 9, Compartmentation.
BS 8313: Code of practice for accommodation of building services in ducts.

The gas meter and its associated controls are the property of the gas authority. It should be sited as close as possible to the service pipe entry to the building, ideally in a purpose-made meter cupboard on the external wall. The cupboard should be positioned to provide easy access for meter maintenance, reading and inspection. The immediate area around the meter must be well ventilated and the meter must be protected from damage, corrosion and heat. A constant pressure governor is fitted to the inlet pipework to regulate the pressure at about 20 mbar (2 kPa or 200 mm w.g.).

Electricity and gas meters should not share the same compartment. If this is unavoidable, a fire resistant partition must separate them and no electrical conduit or cable should be closer than 50 mm to the gas meter and its installation pipework. One exception is the earth equi-potential bond cable. This must be located on the secondary pipework and within 600 mm of the gas meter.



Domestic meter

Gas meters measure the volume of gas in cubic feet or cubic metres consumed within a building. The discharge is converted to kilowatt-hours (kWh). 100 cubic feet or 2·83 cubic metres is approximately 31 kWh, (see page 374). Some older meters have dials but these have been largely superseded by digital displays which are easier to read.

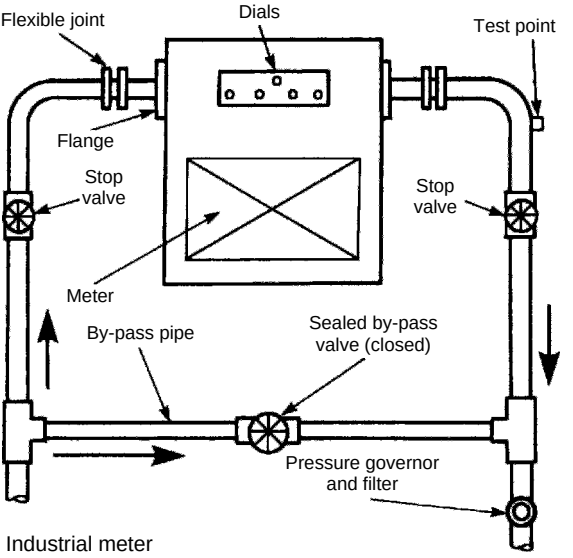
There are basically three categories of meter:

1. Domestic credit.
2. Domestic pre-payment.
3. Industrial credit.

Credit meters measure the fuel consumed and it is paid for after use at 3-monthly billing intervals. Monthly payments can be made based on an estimate, with an annual adjustment made to balance the account.

Pre-payment meters require payment for the fuel in advance by means of coins, cards, key or tokens. Tokens are the preferred method and these are purchased at energy showrooms, post offices and some newsagents. A variation known as the Quantum meter uses a card to record payment. These cards are purchased at designated outlets and can be recharged with various purchase values.

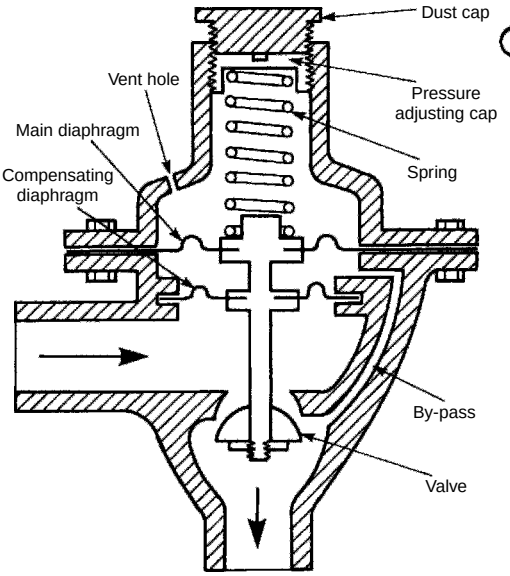
Industrial meters have flanged connections for steel pipework. Flexible connections are unnecessary due to the pipe strength and a firm support base for the meter. A by-pass pipe is installed with a sealed valve. With the supply authority's approval this may be used during repair or maintenance of the meter.



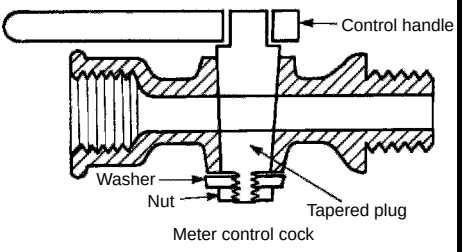
Industrial meter

A constant pressure governor is fitted at the meter to regulate pressure into the system. It is secured with a lead seal to prevent unqualified tampering. Individual appliances may also have factory fitted pressure governors, located just before the burners. Gas passes through the valve and also through the by-pass to the space between the two diaphragms. The main diaphragm is loaded by a spring and the upward and downward forces acting upon this diaphragm are balanced. The compensating diaphragm stabilises the valve. Any fluctuation of inlet pressure inflates or deflates the main diaphragm, raising or lowering the valve to maintain a constant outlet pressure.

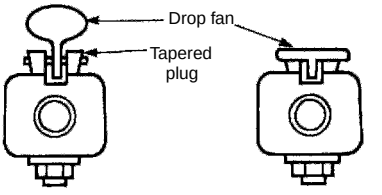
A meter control cock has a tapered plug which fits into a tapered body. As gas pressures are very low, the valve can operate by a simple 90° turn to align a hole in the plug with the bore of the valve body, and vice versa. The drop-fan safety cock prevents the valve being turned accidently.



Constant pressure governor



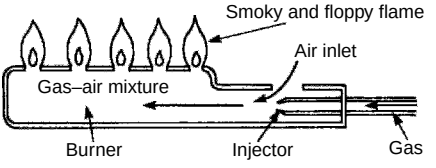
Meter control cock



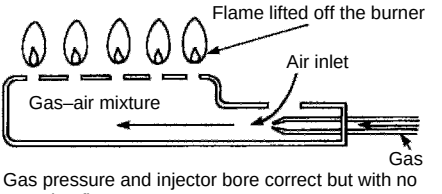
Drop-fan safety cock

For correct combustion of natural gas, burner design must allow for the velocity of the gas-air mixture to be about the same as the flame velocity. Natural gas has a very slow burning velocity, therefore there is a tendency for a flame to lift-off the burner. This must be prevented as it will allow gas to escape, possibly exploding elsewhere! Correct combustion will occur when the gas pressure and injector bore are correct and sufficient air is drawn in, provided the gas-air velocity is not too high to encourage lift-off. Some control over lift-off can be achieved by a retention flame fitted to the burner. Flame lift-off may also be prevented by increasing the number of burner ports to effect a decrease in the velocity of the gas-air mixture. A box-type of burner tray is used for this purpose.

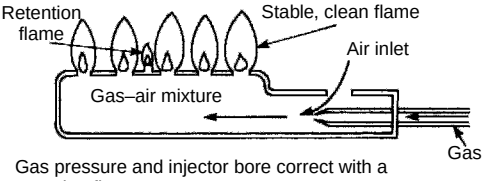
If the gas pressure is too low, or the injector bore too large, insufficient air is drawn into the burner. This can be recognised by a smoky and unstable flame, indicating incomplete combustion and an excess of carbon monoxide. At the extreme, light-back can occur. This is where the flame passes back through the burner to ignite on the injector.



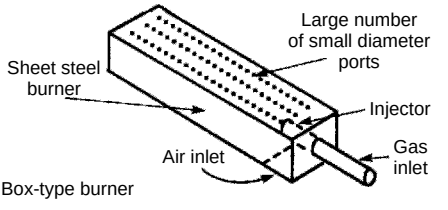
Gas pressure too low or injector bore too large



Gas pressure and injector bore correct but with no retention flame



Gas pressure and injector bore correct with a retention flame



Box-type burner

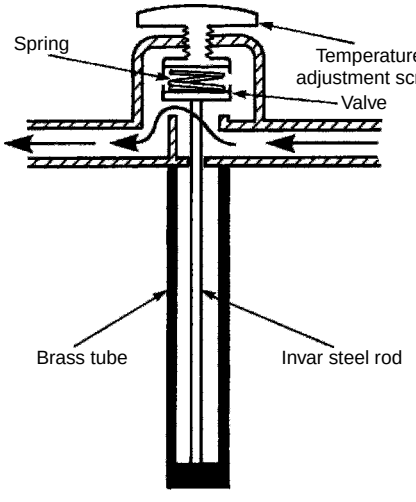
A thermostat is a temperature sensitive device which operates a gas valve in response to a pre-determined setting. Hot water heaters and boilers may be fitted with two thermostats:

1. Working thermostat – controls the water flow temperature from the boiler. It has a regulated scale and is set manually to the user's convenience. It engages or disengages the gas valve at a water temperature of about 80°C.

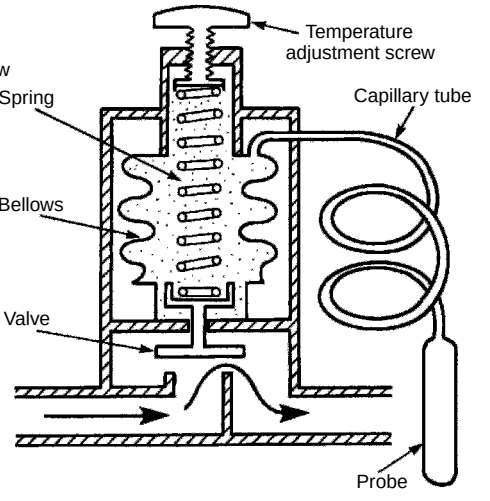
2. High limit thermostat – normally preset by the boiler manufacturer to function at a water temperature of about 90°C. It is a thermal cut-out safety device which will isolate the gas supply if the working thermostat fails.

The rod-type thermostat operates by a difference in thermal response between brass and invar steel. When water surrounding a brass tube becomes hot, the tube expands. This draws the steel rod with it until a valve attached to the rod closes off the fuel supply. The reverse process occurs as the water cools.

The vapour expansion thermostat has a bellows, capillary tube and probe filled with ether. When water surrounding the probe becomes hot, the vapour expands causing the bellows to respond by closing the fuel valve. Cooling water reverses the process.



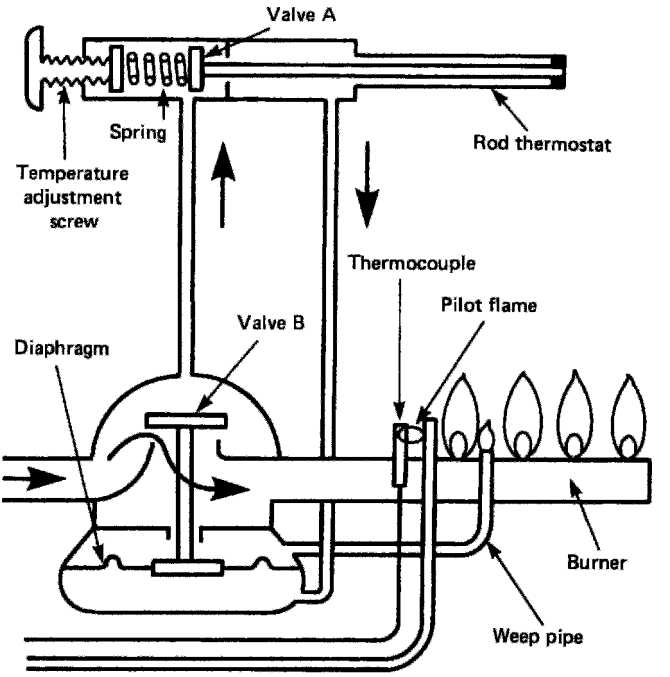
Rod-type thermostat



Vapour expansion thermostat

Gas Boiler Thermostat and Relay Valve

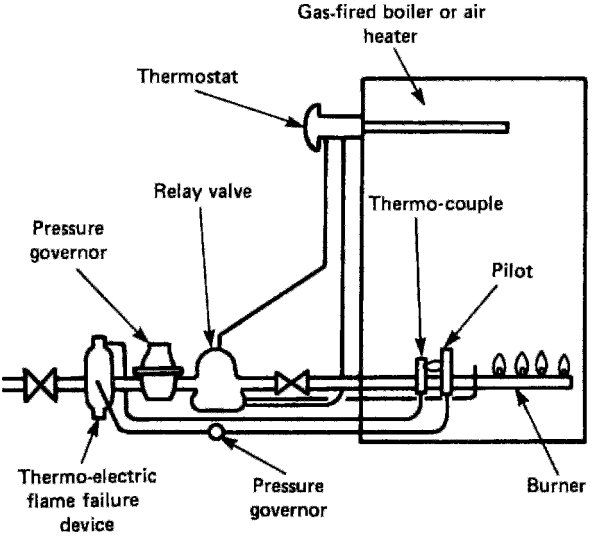
A rod-type thermostat is often connected to a relay valve to control gas supply to the burner. When the boiler is operational, gas flows to the burner because valves A and B are open. Gas pressure above and below the diaphragm are equal. When the water reaches the required temperature, the brass casing of the rod thermostat expands and draws the invar steel rod with it to close valve A. This prevents gas from flowing to the underside of the diaphragm. Gas pressure above the diaphragm increases, allowing valve B to fall under its own weight to close the gas supply to the burner. As the boiler water temperature falls, the brass casing of the thermostat contracts to release valve A which reopens the gas supply.



Operating principles of rod thermostat and gas relay valve

Gas water heaters/boilers and other heat producing appliances such as air heaters must be fitted with a safety device to prevent gas flowing in event of the pilot light extinguishing. Whilst functional, the pilot light plays on a thermo-couple suspended in the gas flame. The hot thermo-couple energises an electromagnetic or solenoid valve to open and allow gas to flow. This is otherwise known as a thermo-electric pilot flame failure safety device. The drawing below shows the interrelationship of controls and the next page illustrates and explains the safety device in greater detail.

To commission the boiler from cold, the thermo-electric valve is operated manually by depressing a push button to allow gas flow to the pilot flame. A spark igniter (see page 347) illuminates the flame whilst the button is kept depressed for a few seconds, until the thermo-couple is sufficiently warm to automatically activate the valve.

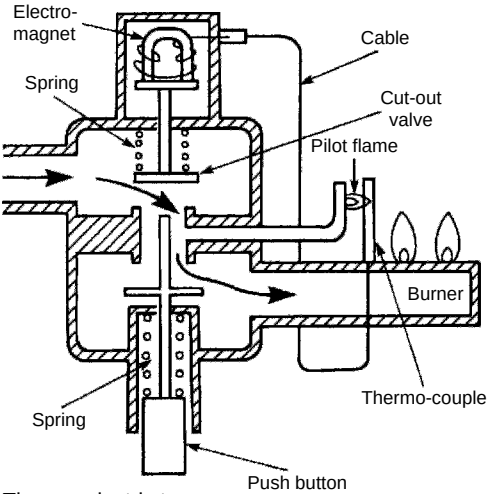


Gas boiler or air heater controls

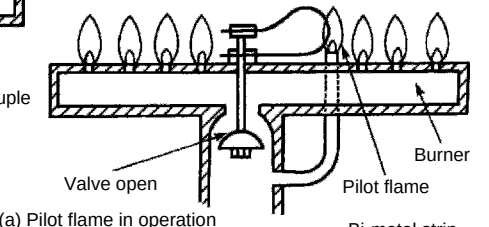
Ref: BS 5258-1: Safety of domestic gas appliances. Specification for central heating boilers and circulators.
BS EN 483: Gas fired central heating boilers.

Thermo-electric – has an ancillary thermo-couple sensing element consisting of two dissimilar metals joined together at each end to form an electrical circuit. When the thermo-couple is heated by the gas pilot flame, a small electric current is generated. This energises an electromagnet in the gas valve which is retained permanently in the open position allowing gas to pass to the relay valve. If the pilot flame is extinguished, the thermo-couple cools and the electric current is no longer produced to energise the solenoid. In the absence of a magnetic force, a spring closes the gas valve.

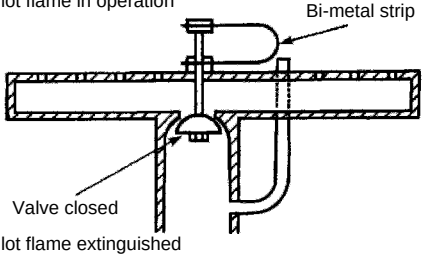
Bi-metallic strip – has a bonded element of brass and invar steel, each metal having a different rate of expansion and contraction. The strip is bent into a U shape with the brass on the outside. One end is anchored and the other attached to a valve. The valve responds to thermal reaction on the strip. If the pilot flame is extinguished, the bent bi-metallic strip contracts opening to its original position and closing the gas supply and vice versa.



Thermo-electric type



(a) Pilot flame in operation

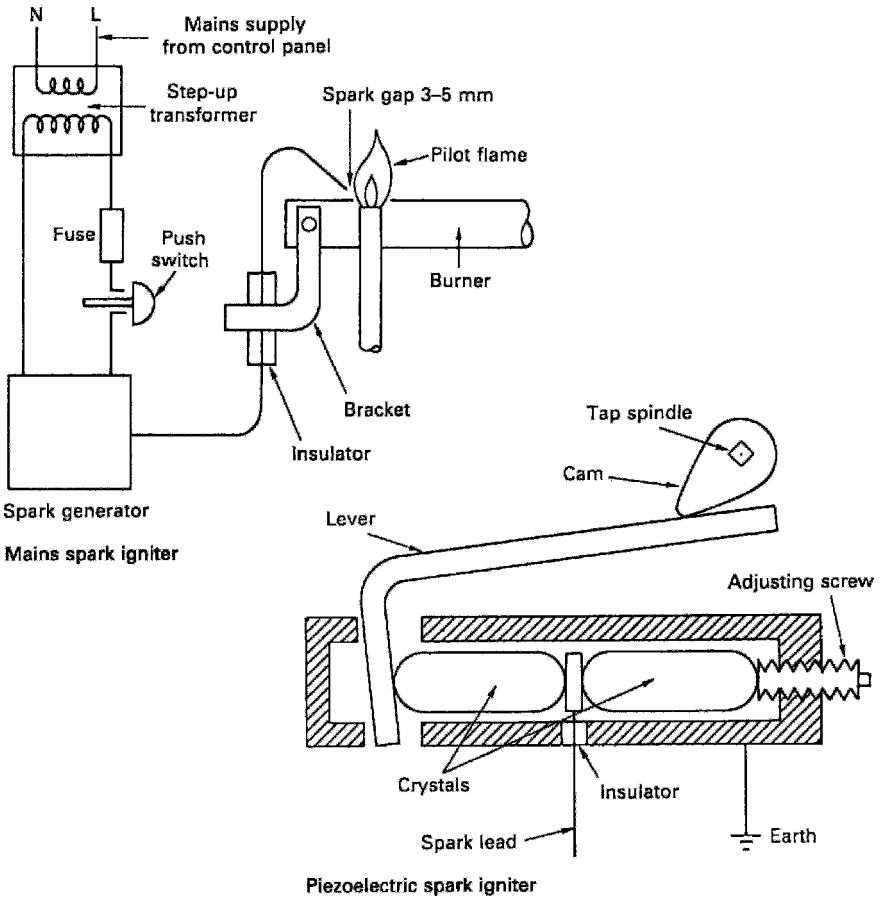


(b) Pilot flame extinguished

Bi-metal type

Lighting the pilot flame with matches or tapers is unsatisfactory. It is also difficult to effect whilst operating the push button control on the gas valve. An integral spark igniter is far more efficient. These are usually operated by mains electricity. An electric charge is compounded in a capacitor, until a trigger mechanism effects its rapid discharge. This electrical energy passes through a step-up transformer to create a voltage of 10 or 15 kV to produce a spark. The spark is sufficient to ignite the pilot flame. Spark generation of this type is used in appliances with a non-permanent pilot flame. This is more fuel economic than a permanent flame. The spark operation is effected when the system thermostat engages an automatic switch in place of the manual push switch shown below and a gas supply to the pilot.

A piezoelectric spark igniter contains two crystals. By pressurising them through a cam and lever mechanism from a push button, a large electric voltage potential releases a spark to ignite the gas.



Purging New Installations

It is very important that new gas installations are thoroughly purged of air and debris that may remain in the completed pipework. This also applies to existing installations that have been the subject of significant changes. If air is not removed, it is possible that when attempting to ignite the gas, a gas–air mixture will cause a blow back and an explosion. Before purging, the system should be pressure tested for leakages – see next page.

Procedure:

- Ensure ample ventilation where gas and air will escape from the system.
- Prohibit smoking, use of electrical switches, power tools, etc. in the vicinity of the process.
- Close the main gas control valve at the meter.
- Disconnect the secondary pipework at the furthest fitting.
  Note: if the last appliance has a flame failure safety device, no gas will pass beyond it, therefore remove its test nipple screw.
- Turn on the main gas control valve until the meter is completely purged.
- Purging the meter is achieved by passing through it a volume of gas at least equal to five times its capacity per revolution of the meter mechanism. Most domestic meters show 0·071 cu. ft. (0·002 m^3) per dial revolution, so: 5 × 0·071 = 0·355 cu. ft. (0·010 m^3) of gas is required.
- Turn off the main gas control valve and reconnect the open end or replace the last appliance test nipple.
- Turn on the main gas control valve and purge any remaining air to branch appliances until gas is smelt.
- Test any previous disconnections by applying soap solution to the joint. Leakage will be apparent by foaming of the solution.
- When all the air in the system has been removed, appliances may be commissioned.

Ref: BS 6891: Installation of low pressure gas pipework of up to 35 mm in domestic premises. Specification.

Testing a new installation:

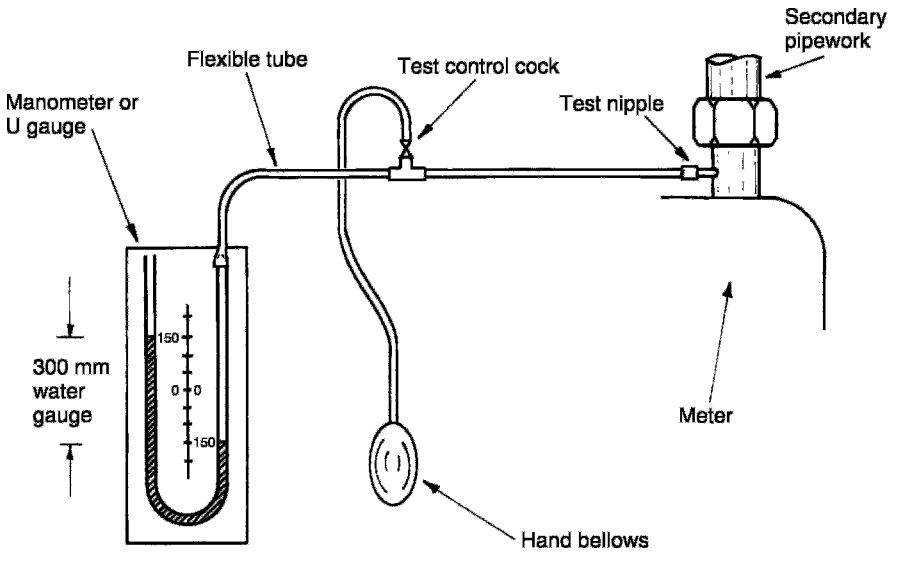
- Cap all open pipe ends and turn appliances off.
- Close the main control valve at the meter. If the meter is not fitted, blank off the connecting pipe with a specially prepared cap and test nipple.
- Remove the test nipple screw from the meter or blanking cap and attach the test apparatus by the rubber tubing.
- Level the water in the manometer at zero.
- Pump or blow air through the test cock to displace 300 mm water gauge (30 mbar) in the manometer. This is approximately one and a half times normal domestic system pressure.
- Wait 1 minute for air stabilisation, then if there is no further pressure drop at the manometer for a further 2 minutes the system is considered sound.
- If leakage is apparent, insecure joints are the most likely source. These are painted with soap solution which foams up in the presence of air seepage.

Testing an existing system:

- Close all appliance valves and the main control valve at the meter.
- Remove the test nipple screw on the meter and attach the test apparatus.
- Open the main control valve at the meter to record a few millimetres water gauge.
- Close the valve immediately and observe the manometer. If the pressure rises this indicates a faulty valve.
- If the valve is serviceable, continue the test by opening the valve fully to record a normal pressure of 200 to 250 mm w.g. Anything else suggests that the pressure governor is faulty.
- With the correct pressure recorded, turn off the main valve, allow 1 minute for air stabilisation and for a further 2 minutes there should be no pressure fluctuation.
- Check for any leakages as previously described.

Manometer or U Gauge

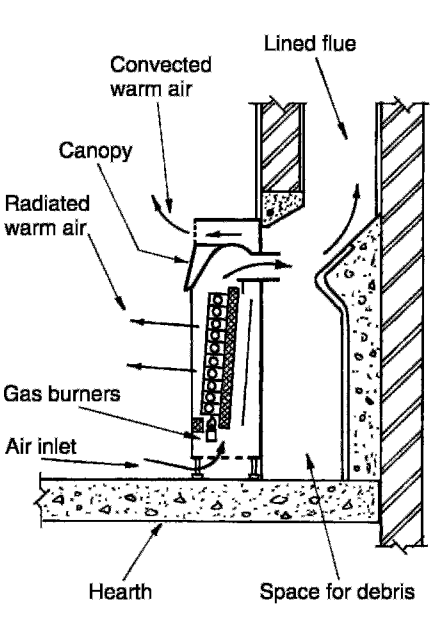
When used with a flexible tube, hand bellows and control cock, this equipment is suitable for measuring gas installation pressure and testing for leakage. It is also suitable for air testing drains and discharge stacks.



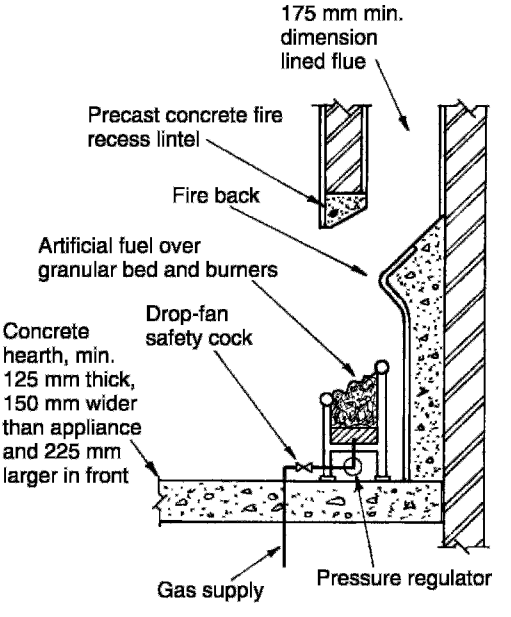
The glass tube is contained in a protective metal or wooden box. It is mounted against a scale graduated in millibars or millimetres. 1 mbar is the pressure exerted by a 9·81 mm (10 mm is close enough) head of water. Water is levelled in the tube to zero on the scale. Care must be taken to note the scale calibration. Some manometers are half scale, which means the measures are in mbar or mm but they are double this to give a direct reading. Others are indirect, as shown. With these, the water displacements either side of the zero must be added.

Fires – these have a relatively low energy rating, usually no more than 3 kW. They are set in a fire recess and use the lined flue for extraction of burnt gases. Air from the room is sufficient for gas combustion, as appliances up to 7 kW net input do not normally require special provision for ventilation. Heat is emitted by convection and radiation.

Decorative fuel effect fires – these are a popular alternative to the traditional gas fire. They burn gas freely and rely on displacement of heat by the colder air for combustion to encourage burnt gas extraction indirectly into the flue. Sufficient air must be available from a purpose-made air inlet to ensure correct combustion of the gas and extraction of burnt gases. An air brick with permanent ventilation of at least 10 000 mm^2 is sufficient for fires up to 12·7 kW net input rating. Log and coal effect fires are designed as a visual enhancement to a grate by resembling a real fire, but as a radiant heater they compare unfavourably with other forms of gas heat emitters.



Gas fire



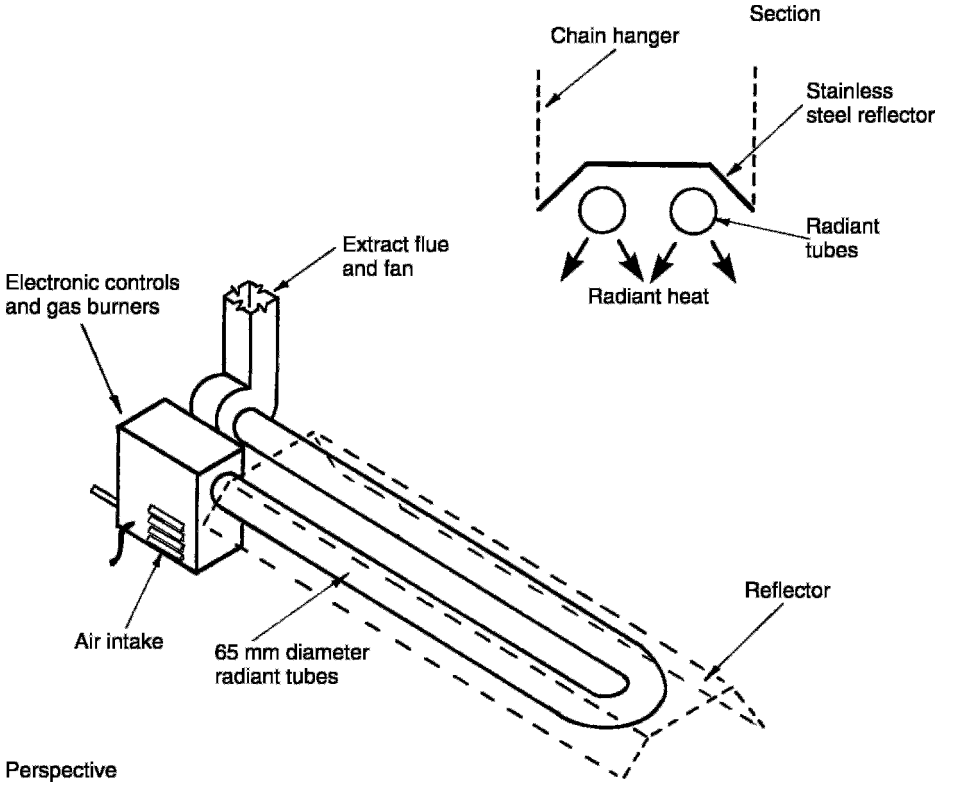
Gas decorative fuel effect fire

Ref: BS 5871: Specification for installation and maintenance of gas fires, convector heaters, fire/back boilers and decorative fuel effect gas appliances. (In 3 parts).

Radiant heaters - in tube format these are simple and effective heat emitters, most suited to high ceiling situations such as industrial units, warehouses and factories. They suspend above the work area and provide a very efficient downward radiation of up to 40 kW. Gas is fired into one end of a tube and the combustion gases extracted by fan assisted flue at the other. The tube may be straight or return in a U shape to increase heat output. A polished stainless steel back plate functions as a heat shield and reflector.

The control box houses an air intake, electronic controls, gas regulators and safety cut-out mechanisms. This includes a gas isolator in event of fan failure. To moderate burning, the end of the tube has a spiral steel baffle to maintain even temperature along the tube.

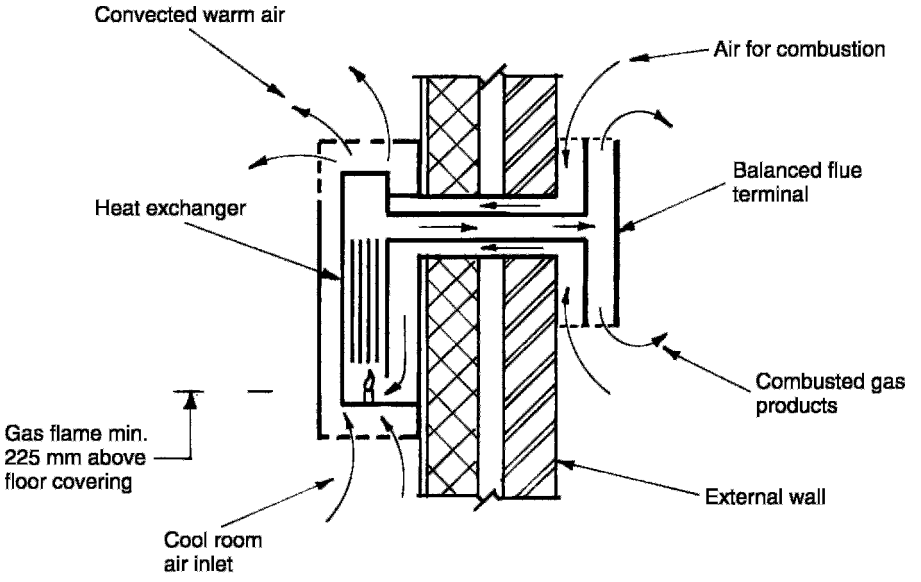
Advantages over other forms of heating include a rapid heat response, low capital cost, easy maintenance and high efficiency.



Convector – a wall mounted, balanced flue appliance rated up to about 7 kW. They are compact units, room sealed and therefore independent of natural draught from the room in which they are installed. The flue is integral with the appliance and must be installed on an external wall. An exception is when the flue is fan assisted, as this will permit a short length of horizontal flue to the outside wall.

Air for combustion of gas is drawn from outside, through a different pathway in the same terminal as the discharging combusted gases. Correct installation will ensure that the balance of air movement through the terminal is not contaminated by exhaust gases.

About 90% of the heat emitted is by convection, the remainder radiated. Some convectors incorporate a fan, so that virtually all the heat is convected.

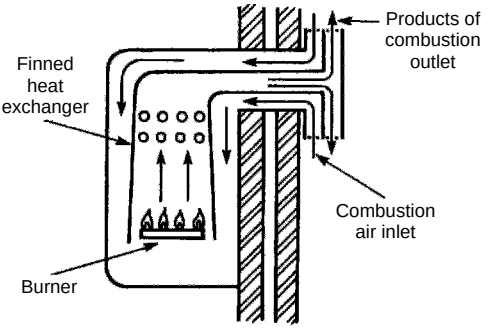


Room sealed gas convector heater

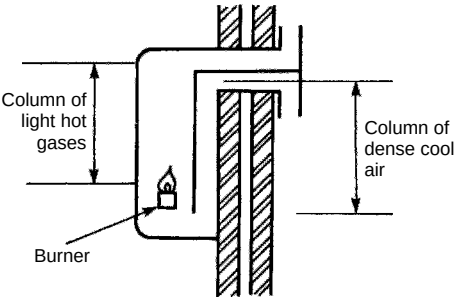
Refs: Building Regulations, Approved Document J: Combustion appliances and fuel storage systems.
BS 5440-1: Installation and maintenance of flues and ventilation for gas appliances of rated input not exceeding 70 kW net. Specification.

The balanced flue appliance has the air inlet and flue outlet sealed from the room in which it is installed. It is more efficient than a conventional open flue pipe as there are less heat losses in and from the flue. As it is independent of room ventilation there are no draughts associated with combustion and there is less risk of combustion products entering the room. It is also less disruptive to the structure and relatively inexpensive to install.

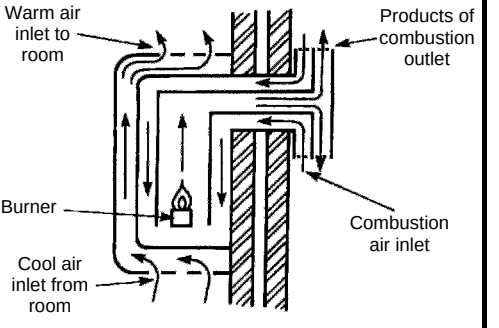
A balanced flue is designed to draw in the air required for gas combustion from an area adjacent to where it discharges its combusted gases. These inlets and outlets must be inside a windproof terminal sited outside the room in which the appliance is installed. Gas appliances in a bath or shower room, or in a garage must have balanced flues.*



Balanced flue water heater



Principle of operation of the balanced flue heater

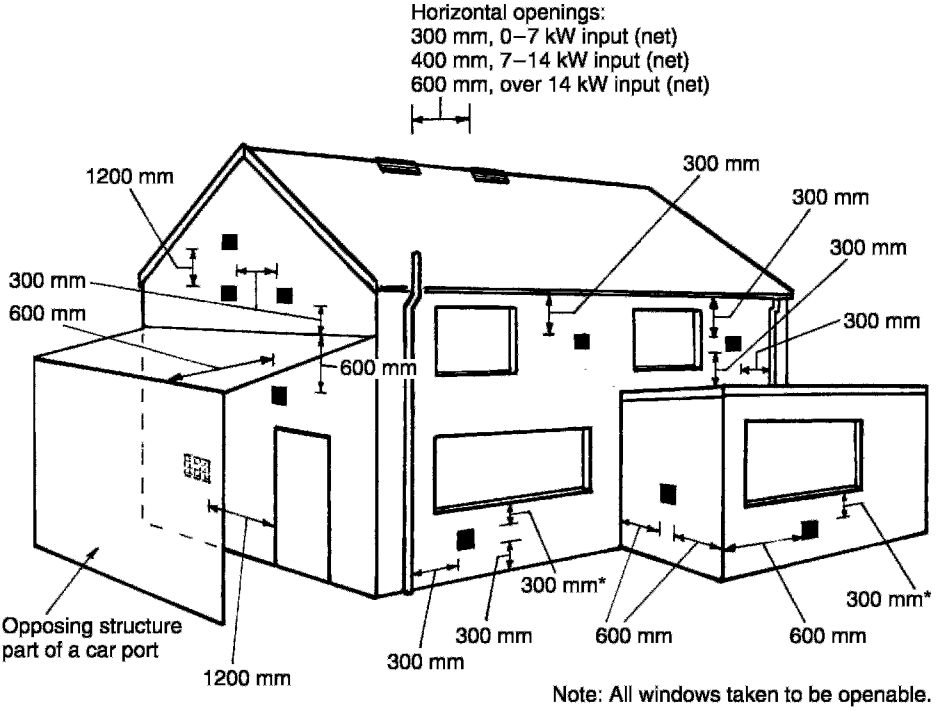


Balanced flue convector heater

* Ref: Gas Safety (Installation and Use) Regulations.

Balanced flue terminals must be positioned to ensure a free intake of air and safe dispersal of combustion products. Generally, they should be located on a clear expanse of wall, not less than 600 mm from internal or external corners and not less than 300 mm below openable windows, air vents, grilles, gutters or eaves.

A terminal less than 2 m from ground level should be fitted with a wire mesh guard to prevent people contacting with the hot surface. Where a terminal is within 600 mm below a plastic gutter, an aluminium shield 1·5 m long should be fitted to the underside of the gutter immediately above the terminal.



*0–7 kW input (net) – 300 mm, 7–14 kW input (net) – 600 mm, 14–32 kW input (net) – 1500 mm, over 32 kW input (net) – 2000 mm
Balanced flue and ridge natural draught terminal positions (min. dimensions)

Refs: Building Regulations, Approved Document J: Section J3, Protection of Building.
BS 5440-1: Installation and maintenance of flues and ventilation for gas appliances of rated input not exceeding 70 kW net. Specification.

Natural draught flues – appliances discharging flue gases by natural convection are located on an external wall. There must be some regard for the adjacent construction as unsatisfactory location may result in:

- inefficient combustion of fuel
- risk of fire
- combustion products staining the wall
- combustion gases entering the building.

Fan assisted flues – appliances fitted with these can be located a short distance from an external wall. Smaller terminals are possible due to the more positive extraction of the flue gases. Terminal location is not as critical as for natural draught flues, but due regard must still be given to adjacent construction.

Location of balanced flue terminals (min. distance in mm):

Location of terminal	Natural draught	Fan assisted
Directly under an openable window or a ventilator	300*	300
Under guttering or sanitation pipework	300	75
Under eaves	300	200
Under a balcony or a car port roof	600	200
Horizontally to an opening	As ridge openings window shown previous page	300
Opening in a car port	1200	1200
Horizontally from vertical drain and discharge pipes	300	150 75 < 5 kW input (net)
Horizontally from internal or external corners	600	300
Above ground, balcony or flat roof	300	300
From an opposing wall, other surface or boundary	600	600
Opposite another terminal	600	1200
Vertically from a terminal on the same wall	1200	1500
Horizontally from a terminal on the same wall	300	300

* See note on previous page.

Installation must be with regard to the intrusive characteristic volume of flue gases that discharge in the form of a plume of moisture droplets. In addition to the flue location guidance given on the previous two pages, a horizontal discharge is not permitted within 2·5 m of an opposing wall, a boundary fence or a neighbouring property. A vertical and/or horizontal flue pipe extension may be used to avoid these restrictions. Further, the plume should not intrude:

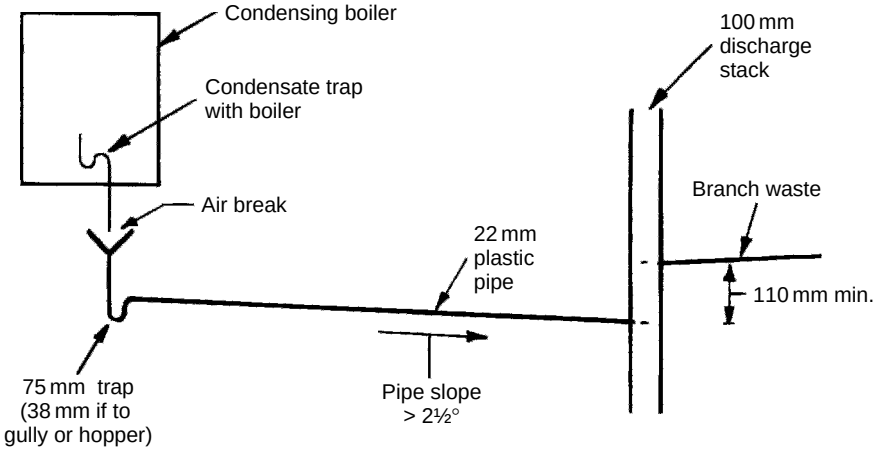
- into a car port
- over a frequently used pedestrian area, such as an access route, a patio or a terrace (see *Note*)
- over a vehicle access route or car parking area (see *Note*)

Note: An exception is where the flue discharge is at least 2·1 m above surface or ground level.

Drainage of the condensation produced by the boiler must also be considered. The condensate can amount to as much as 4 litres in a day, and as it is slightly acid (pH 3–6, see page 3), it must be suitably disposed of. The most convenient means for disposal may be:

- to a waste pipe connecting to an internal stack
- into an external gully or rainwater hopper that connect to a combined drainage system
- into a purpose-made soakaway

Condensate pipes must be fitted with a water seal trap of at least 38 mm depth if discharging to an open gully or rainwater hopper. The seal must be 75 mm when the condensate pipe connects directly to a sanitation system waste pipe or discharge stack. The principles are as shown below.



Where gravity discharge is impractical, e.g. from a boiler located in a basement, condensate may be pumped from a sump collector.

Conventional Open Flue for a Gas Burning Appliance – 1

A gas appliance may be situated in a fire recess and the chimney structure used for the flue. The chimney should have clay flue linings to BS EN 1457: Chimneys – Clay/ceramic flue liners. A stainless steel flexible flue lining may be installed where the chimney was built before 1 February 1966, provided the lining complies with BS EN 1856-2: Chimneys. Requirements for metal chimneys. Metal liners and connecting flue pipes.

Other suitable flue materials include:

- precast hollow concrete flue blocks to BS EN 1858.
- pipes made from stainless steel (BS 1449), enamelled steel (BS 6999), cast iron (BS 41) or fibre cement (BS 567 or 835)
- products that satisfy an acceptable quality standard, such as that awarded by the British Board of Agrément.
- fibre cement pipes and other concrete products to BS EN 1857.

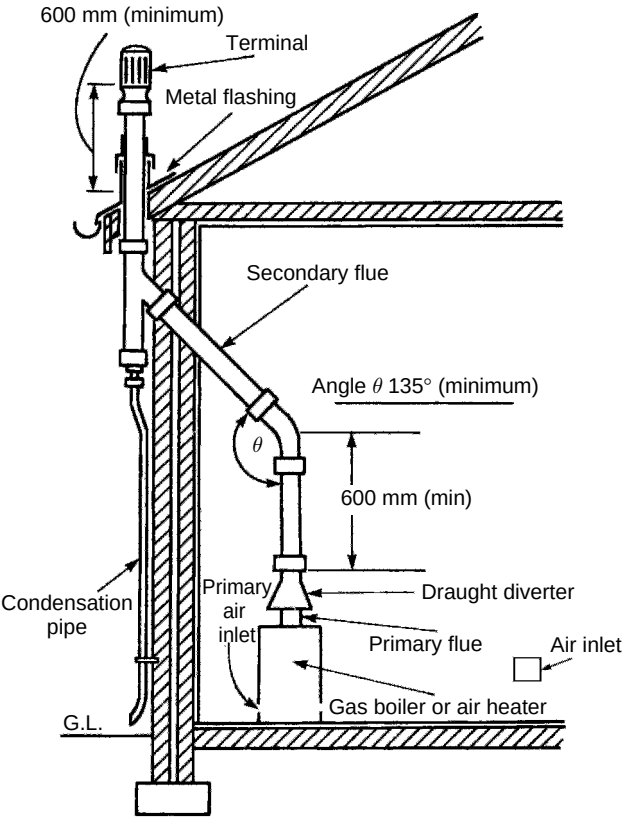
Flues must be correctly sized from appliance manufacturer's data, see pages 376 to 378. If a flue is too large or too long, overcooling of the flue gases will produce condensation. This occurs at about 60°C when the gases cool to the dew point of water. The following factors will determine the flue size:

- heat input to the appliance
- resistance to the flow of combustion gases caused by bends and the terminal
- length of the flue.

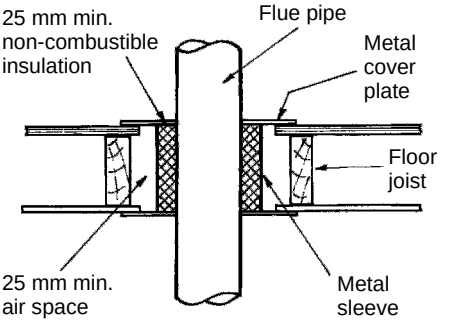
Spigot and socket flue pipes are installed socket uppermost and joints made with fire cement. For the efficient conveyance of combusted gases, flue pipes should be vertical wherever possible. Where they pass through a floor or other combustible parts of the structure they should be fitted with a non-combustible sleeve.

A ventilation opening (air brick) for combustion air is required in the external wall of the room containing the appliance. As a guide, for large boilers in their own plant room a ventilation-free area of at least twice the flue area is required. For domestic appliances, 500 mm^2 for each kilowatt of input rating over 7 kW net is adequate.

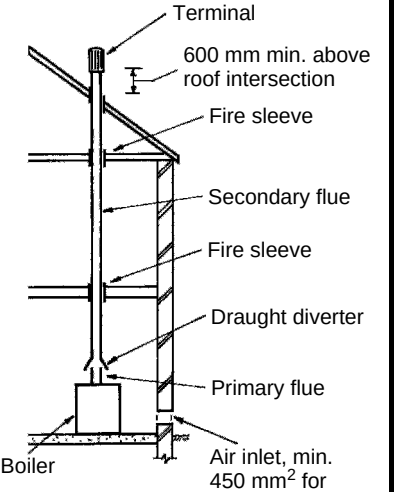
Ref: Building Regulations, Approved Document J: Combustion appliances and fuel storage systems. Section J3: Protection of building.



Installation of flue

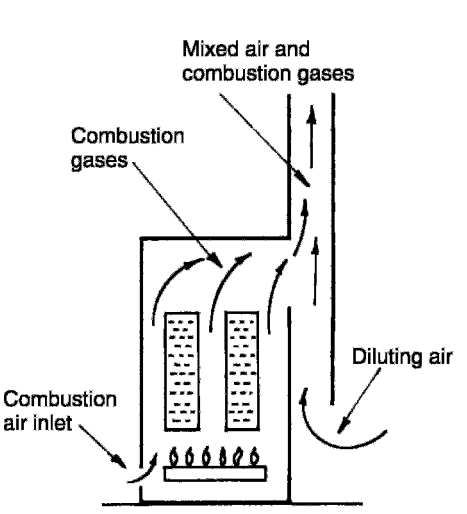


Fire sleeve

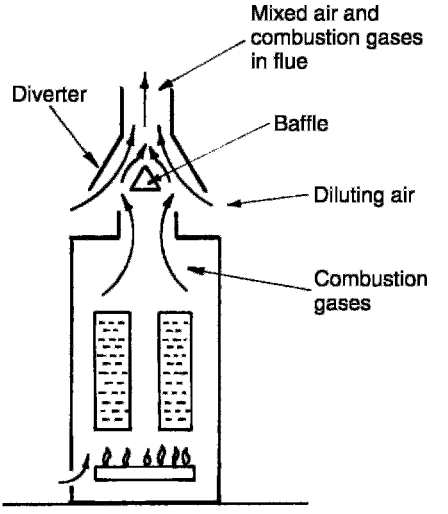


Vertical open flue

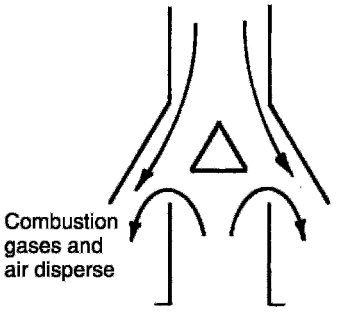
The purpose of a draught diverter is to admit diluting air into the primary flue to reduce the concentration of combustion gases and to reduce their temperature in the flue. The draught diverter, as the name suggests, also prevents flue downdraughts from extinguishing the gas pilot flame by diverting the draughts outside of the burners. Draught diverters can be provided in two ways. Either as an open lower end to the flue (integral) or an attachment (separate) to the primary flue.



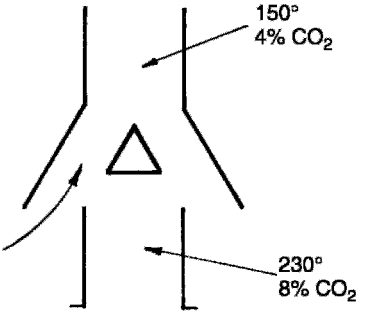
Integral diverter



Separate diverter



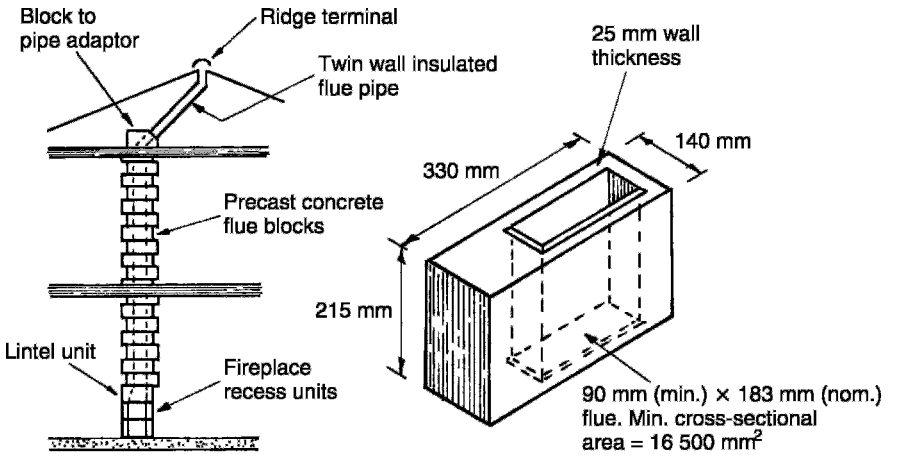
Action during downdraught

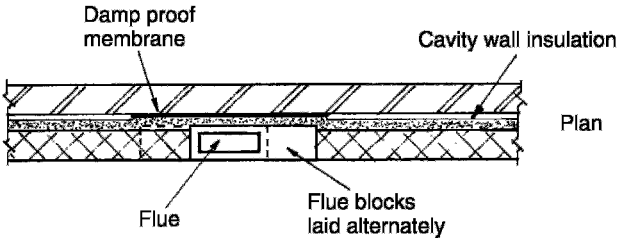


Temperatures and carbon dioxide content during normal operation

Precast concrete flue blocks are manufactured from high alumina cement and dense aggregates, to resist the effects of toxic flue gases and condensation. They are jointed with high alumina cement mortar and laid alternately and integrally with the inner leaf of concrete blockwork in a cavity wall. This optimises space and appearance, as there is no chimney structure projecting into the room or unsightly flue pipe. The void in the blocks is continuous until it joins a twin wall insulated flue pipe in the roof space to terminate at ridge level.

These flue blocks are specifically for gas fires and convectors of relatively low rating. Whilst a conventional circular flue to a gas fire must be at least 12 000 mm^2 cross-sectional area, these rectangular flue blocks must have a minimum flue dimension of 90 mm and cross-sectional area of 16 500 mm^2.





Ref: BS EN 1858: Chimneys. Components. Concrete flue blocks.

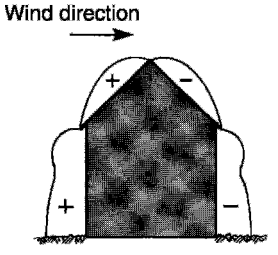
A flue terminal has several functions:

- to prevent entry of birds, squirrels, etc.
- to prevent entry of rain and snow
- to resist the effects of downdraughts
- to promote flue pull and extraction of combusted gases.

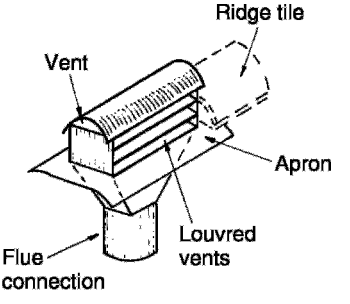
Location – should be with regard to positive and negative wind pressures acting on a roof to permit free wind flow across the terminal and not be too close to windows and other ventilation voids. The preferred location is at or above the ridge of a pitched roof. Elsewhere, the following can be used as guidance:

Location	Min. height (mm) to lowest part of outlet
Within 1·5 m horizontally of a vertical surface, e.g. dormer	600 above top of structure
Pitched roof <45°	600 from roof intersection
Pitched roof >45°	1000 " " "
Flat roof	250 " " "
Flat roof with parapet*	600 " " "

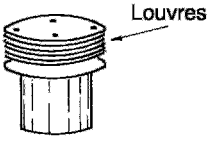
* Note: if horizontal distance of flue from parapet is greater than 10 × parapet height, min. flue height = 250 mm.

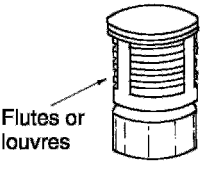


Pressure zones to avoid for open flue terminals



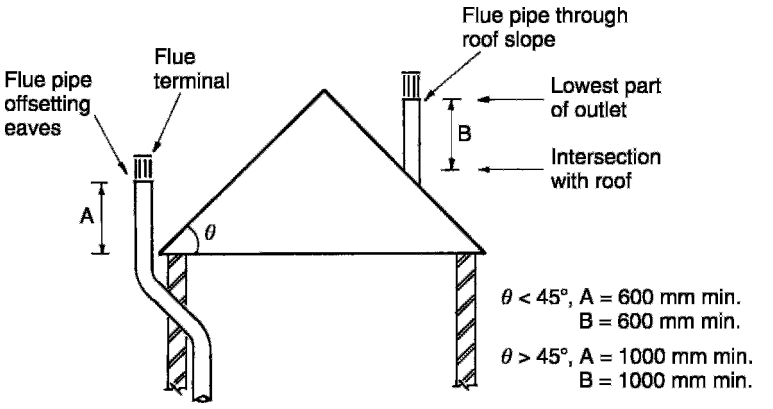
Ridge terminal



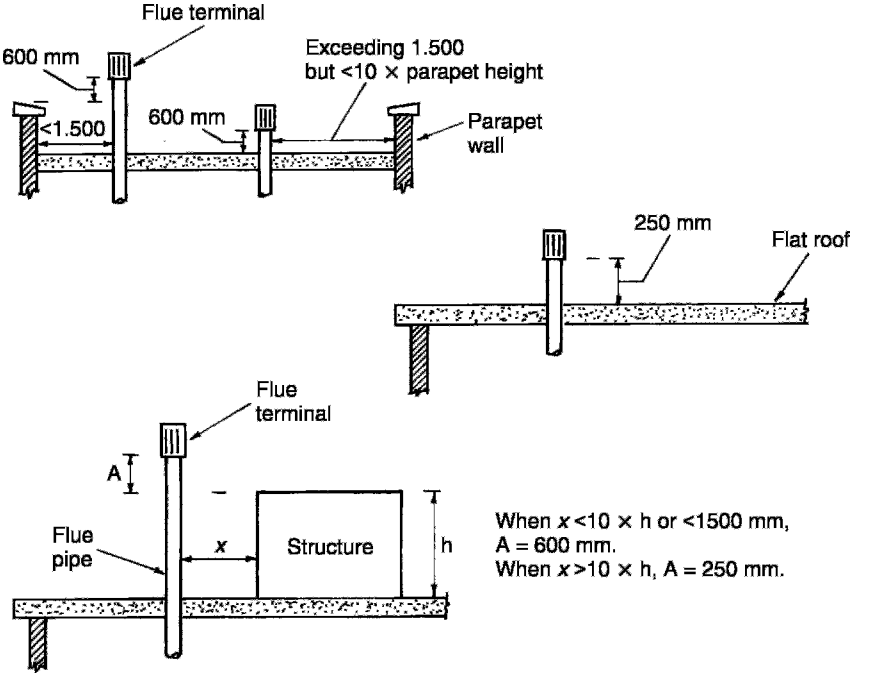


Flue pipe terminals

Pitched roof:



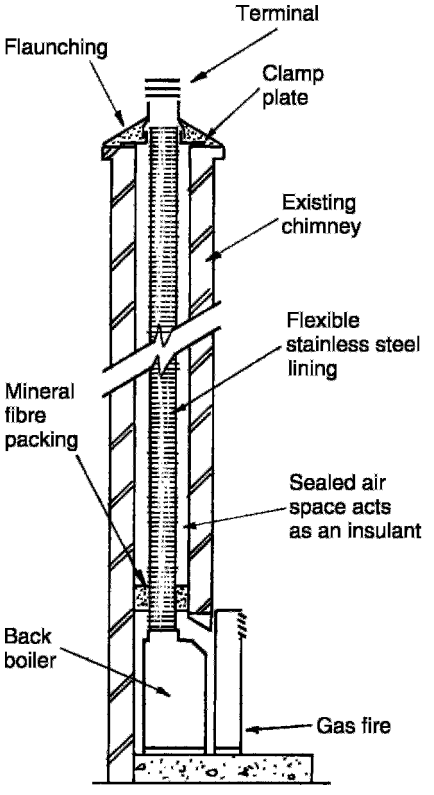
Flat roof:

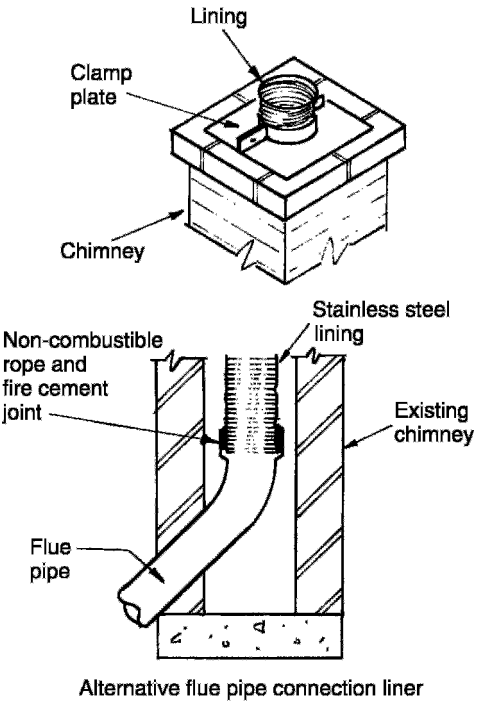


Ref: BS 5440-1: Installation and maintenance of flues and ventilation for gas appliances of rated input not exceeding 70 kW net. Specification.

Traditional brick chimneys have unnecessarily large flues when used with gas burning appliances. If an existing unlined chimney is to be used, a flexible stainless steel lining should be installed to prevent the combustion products and condensation from breaking down the old mortar joints. By reducing the flue area with a lining, this will accelerate the discharge of gases (efflux velocity), preventing them from lowering sufficiently in temperature to generate excessive condensation.

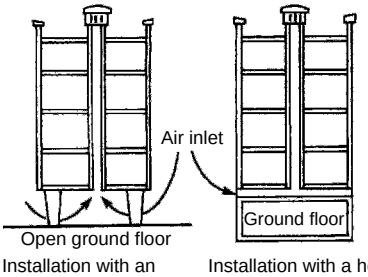
Coils of stainless steel lining material are available in 100, 125 and 150 mm diameters to suit various boiler connections. The existing chimney pot and flaunching are removed to permit the lining to be lowered and then made good with a clamping plate, new flaunching and purpose-made terminal.





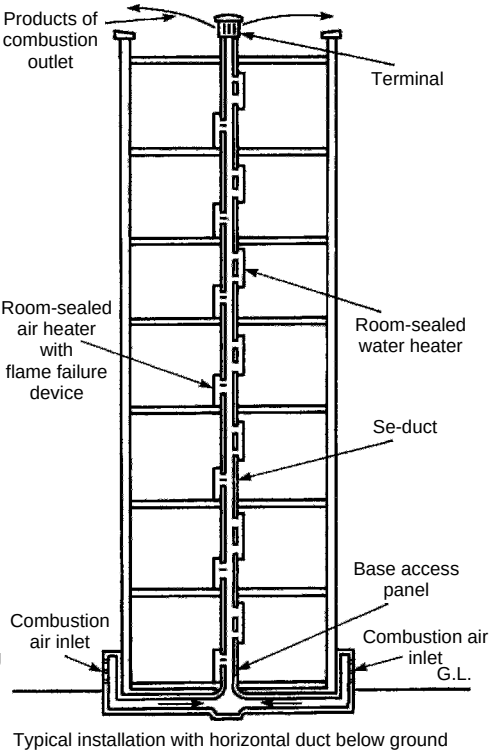
Alternative flue pipe connection liner

This is a cost-effective alternative to providing a separate flue for each gas appliance installed in a multi-storey/multi-unit building. It was originally developed by the South-east Gas Board to utilise balanced flues attached to a central ventilated void. Appliances use a central duct for air supply to the gas burners and to discharge their products of combustion. The dilution of burnt gases must be sufficient to prevent the carbon dioxide content exceeding 1·5% at the uppermost appliance. The size of central void depends on the number of appliances connected. Tables for guidance are provided in BS 5440-1: Installation and maintenance of flues and ventilation for gas appliances of rated input not exceeding 70 kW net. Specification.



Installation with an open ground floor

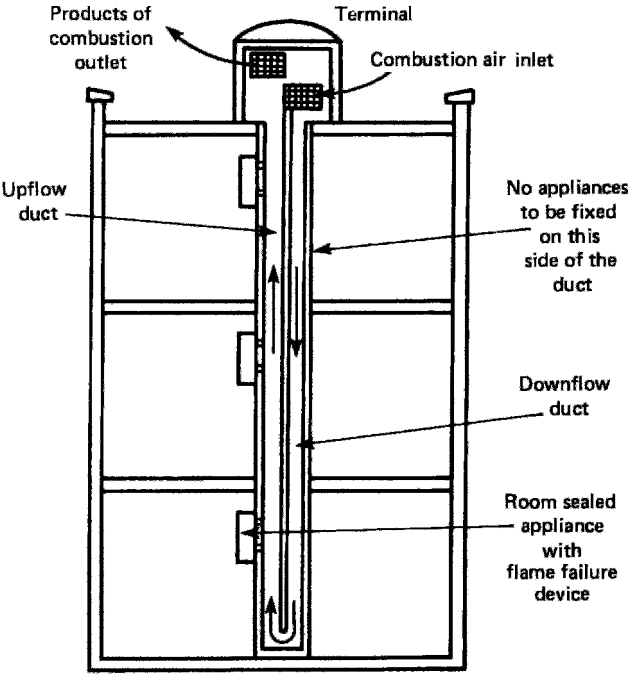
Installation with a horizontal duct in the ground floor ceiling



Typical installation with horizontal duct below ground

Note: A flame failure device is otherwise known as a flame supervision device.

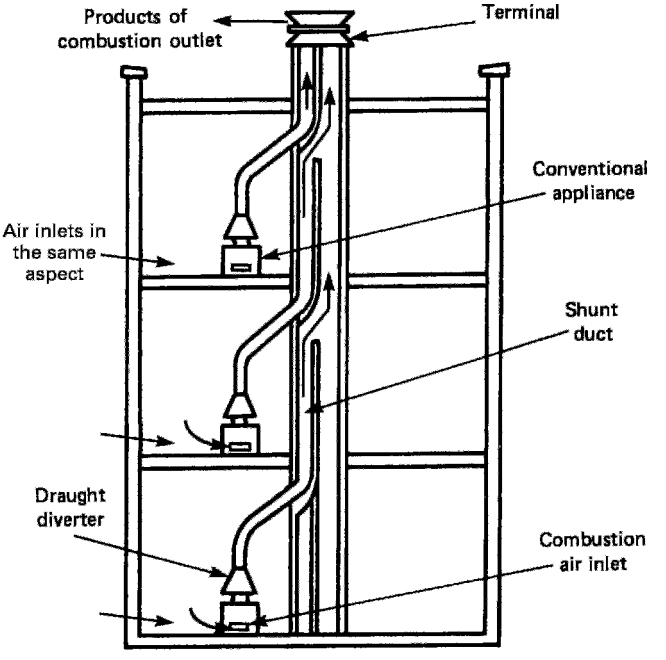
The U duct system is similar in concept to the Se-duct, but used where it is impractical to supply air for combustion at low level. The U duct has the benefits of the Se-duct, but it will require two vertical voids which occupy a greater area. The downflow duct provides combustion air from the roof level to appliances. Appliances of the room sealed-type are fitted with a flame failure/supervision device to prevent the build-up of unburnt gases in the duct. They can only connect to the upflow side of the duct. Stable air flow under all wind conditions is achieved by using a balanced flue terminal, designed to provide identical inlet and outlet exposure. As with the Se-duct, the maximum amount of carbon dioxide at the uppermost appliance inlet must be limited to 1·5%.



Typical installation of U duct

The shunt duct system is applicable to installation of several conventional appliances with open flues in the same building. It economises in space and installation costs when compared with providing each appliance with an individual flue. It is limited to ten consecutive storeys due to the effects of varying wind pressures and each appliance must be fitted with a draught diverter and a flame failure/supervision device. Gas fires and water heaters may be connected to this system, provided the subsidiary flue from each is at least 1·2 m and 3 m long respectively, to ensure sufficient draught.

Other shared flue situations may be acceptable where conventional open flued appliances occupy the same room. Consultation with the local gas authority is essential, as there are limitations. An exception is connection of several gas fires to a common flue. Also, a subsidiary branch flue connection to the main flue must be at least 600 mm long measured vertically from its draught diverter.

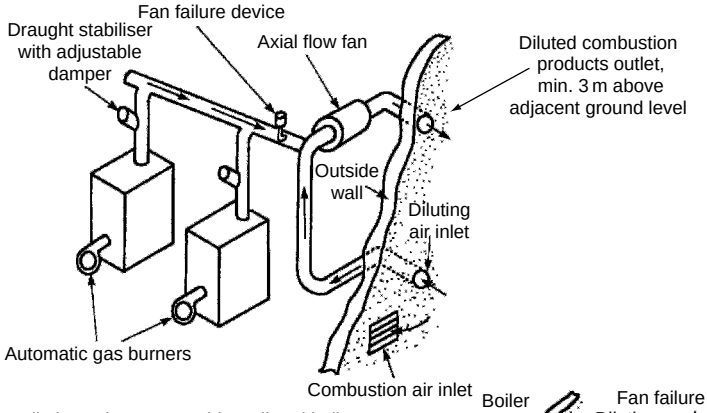


Typical installation of shunt duct

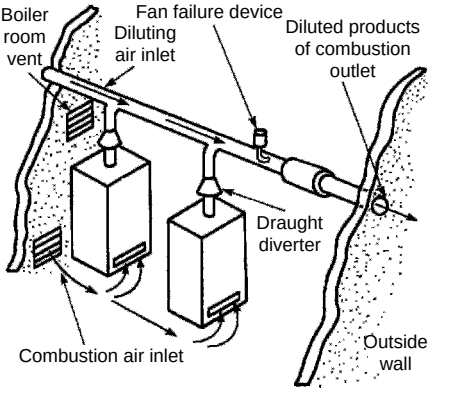
Note: Shared flues sized in accordance with BS 5440-1.

With high rise shops, office buildings and flats sharing the same boiler, problems can arise in providing a flue from ground floor plant rooms. Instead of extending a vertical flue from ground level to the top of a building, it is possible to air dilute the flue gases and discharge them at relatively low level by installing an extract fan in the flue. As the boiler fires, the fan draws fresh air into the flue to mix with the products of gas combustion and to discharge them to the external air. The mixed combustion gases and diluting air outlet terminal must be at least 3 m above ground level and the carbon dioxide content of the gases must not exceed 1%. A draught sensor in the flue functions to detect fan operation. In the event of fan failure, the sensor shuts off the gas supply to the boilers.

The plant room is permanently ventilated with air bricks or louvred vents to ensure adequate air for combustion. Ventilation voids should be at least equivalent to twice the primary flue area.



Installation using one outside wall and boilers with automatic burners



Diluted flue gases:
Max. temperature 50°C.
Velocity, 6–7 m/s.
CO_2 content, max. 1%.

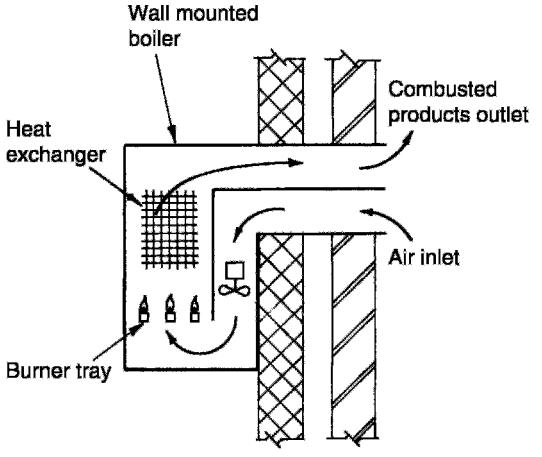
Installation, using two outside walls and boilers with draught diverters

Fan assistance with the dilution and removal of combustion products has progressed from commercial and industrial applications in open flues, to domestic appliance balanced flues. In addition to diluting the CO_2 content at the flue gases point of discharge, fanned draught balanced flue systems have the following advantages over standard balanced flues:

- Positive control of flue gas removal without regard for wind conditions.
- Location of flue terminal is less critical – see page 356.
- Flue size (inlet and outlet) may be smaller.
- Flue length may be longer, therefore the boiler need not be mounted on an external wall.
- Heat exchanger may be smaller due to more efficient burning of gas. Overall size of boiler is reduced.

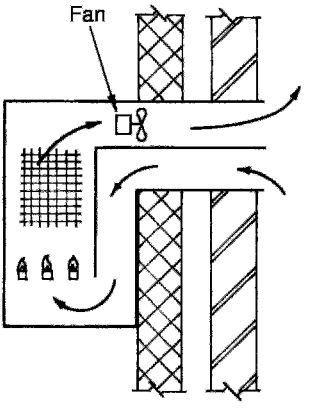
The disadvantages are, noise from the fan and the additional features could make the appliance more expensive to purchase and maintain.

If the fan fails, the air becomes vitiated due to lack of oxygen and the flames smother. The flame failure/protection device then closes the gas valve.



Fan at inlet

Note: Fan may deliver air only to combustion chamber, or an air/gas mixture



Fan at outlet

Note: Fan will be specifically designed to withstand high flue gas temperatures

Location of fan

Room sealed balanced flue appliances do not require a purpose-made air vent for combustion as the air supply is integral with the terminal. Where installed in a compartment or in an enclosure such as a cupboard an air vent is necessary to remove excess heat. With open or conventional flue appliances, access must be made for combustion air if the appliance input rating is in excess of 7 kW (net). This equates to at least 500 mm^2 of free area per kW over 7 kW (net), e.g. the ventilation area required for an open flued boiler of 20 kW (net) input rating will be at least 20–7 = 13 × 500 = 6500 mm^2.

Conventionally flued appliances will also require air for cooling if they are installed in a compartment. This may be by natural air circulation through an air brick or with fan enhancement.

Flueless appliances such as a cooker or instantaneous water heater require an openable window direct to outside air, plus the following ventilation grille requirements:

Oven, hotplate or grill:

Room volume (m^3)	Ventilation area (mm^2)
<5	10 000
5–10	5000 (non-required if a door opens directly to outside air)
>10	non-required

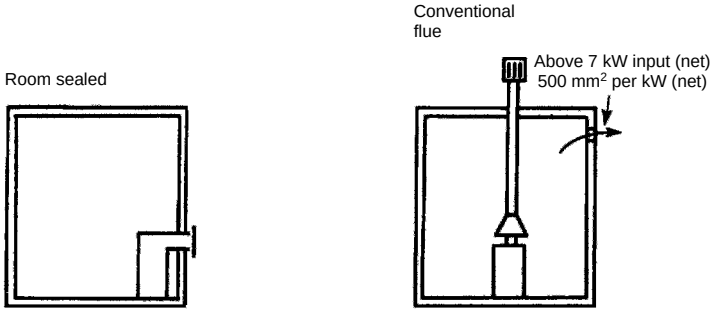
Instantaneous water heater (max. input 11 kW (net)):

Room volume (m^3)	Ventilation area (mm^2)
<5	not permitted
5–10	10 000
10–20	5000
>20	non-required

Vents should be sited where they cannot be obstructed. At high level they should be as close as possible to the ceiling and at low level, not more than 450 mm above floor level. When installed between internal walls, vents should be as low as possible to reduce the spread of smoke in the event of a fire.

Open flued gas fires rated below 7 kW (net) require no permanent ventilation, but decorative fuel effect fires will require a vent of at least 10 000 mm^2 free area.

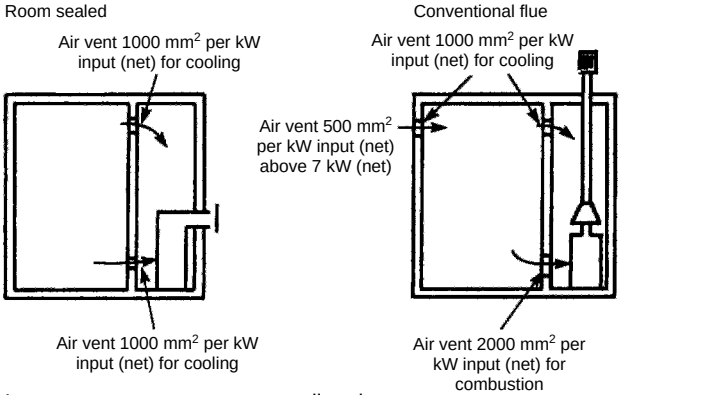
The next page illustrates requirements for room sealed and open flued appliances.



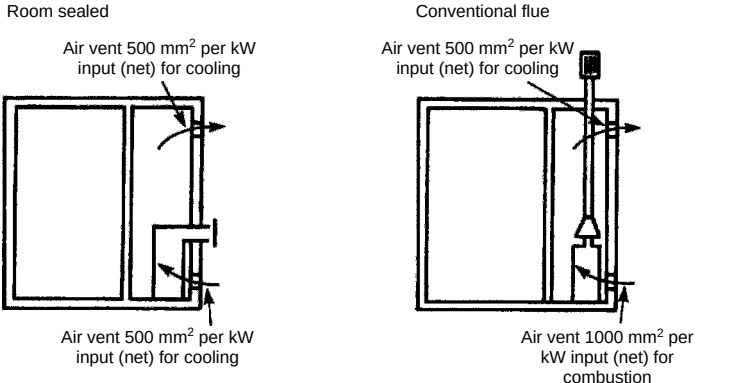
No vent required for the appliance

Below 7 kW no vent required

In a room



In a compartment open to a ventilated room

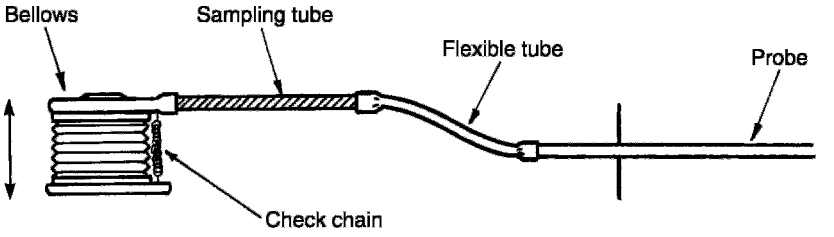


In a compartment open to the outside

Refs: Building Regulations, Approved Document J: Combustion appliances and fuel storage systems.
BS 5440-1: Installation and maintenance of flues and ventilation for gas appliances of rated input not exceeding 70 kW net. Specification.

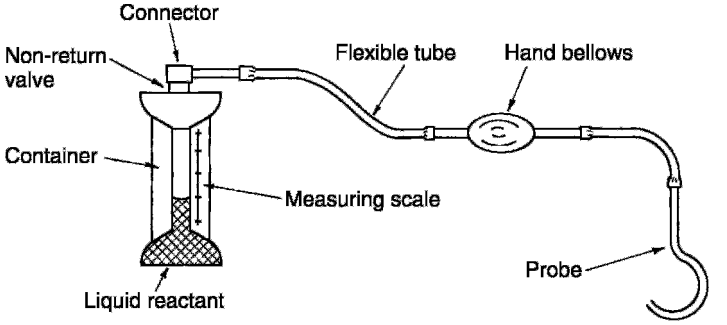
Simple field tests are available to assess the efficiency of gas combustion with regard to the percentage of carbon monoxide and carbon dioxide in the flue gases.

Draeger analyser – hand bellows, gas sampler tube and a probe. The tube is filled with crystals corresponding to whether carbon monoxide or carbon dioxide is to be measured. The probe is inserted into the flue gases and the bellows pumped to create a vacuum. The crystals absorb different gases and change colour accordingly. Colours correspond with a percentage volume.



Draeger flue gas analyser

Fyrite analyser – hand bellows, container of liquid reactant and a probe. Flue gases are pumped into the container which is inverted so that the liquid reactant absorbs the gas in solution. The liquid rises to show the percentage carbon dioxide corresponding to a scale on the container. Oxygen content can also be measured using an alternative solution.



Fyrite CO_2 analyser

Note: Flue gas samples can be taken by inserting the probe below the draught diverter or through the access plate on top of the appliance combustion chamber. Samples can also be taken at the terminal. The above apparatus is retained to illustrate the principles of probe testing. Modern LCD hand held units are now in general use and have the benefit of determining flue gas temperature, O_2, CO and CO_2 content.

The rate of gas flowing in a pipe can be calculated by applying Pole's formula. This is a variation of the D'Arcy fluid flow formula shown on pages 33 and 34.

Pole's formula can be expressed as:

$$q = 0{\cdot}001978 \times d^2 \times \sqrt{(h \times d) \div (s \times l)} = \text{litres per second (l/s)}$$

$$Q = 0{\cdot}0071 \times \sqrt{(h \times d^5) \div (s \times l)} = \text{cubic metres per hour } (m^3/h)$$

where: 0·001978 and 0·0071 are constant friction coefficients

h = pressure loss in millibars (mb)

d = pipe diameter (mm)

s = specific gravity of gas (natural gas approx. 0·6)

l = length of pipe conveying gas (m)

The second formula is usually favoured. This provides a figure compatible with gas consumed by an appliance, in m^3/h.

For example, determine the gas flow rate in a 10 m length of 15 mm o.d. copper tube (13·5 mm i.d.) with an acceptable pressure loss of 1 mb.

$$Q = 0{\cdot}0071 \times \sqrt{(1 \times 13{\cdot}5^5) \div (0{\cdot}6 \times 10)}$$

$$Q = 0{\cdot}0071 \times 273{\cdot}3749 = 1{\cdot}941\ m^3/h$$

Pole's formula can be rearranged to make pressure loss (h) the subject:

$$h = (Q^2 \times s \times l) \div (d^5 \times 0{\cdot}0071^2)$$

It can be seen that the pressure loss (h) is directly proportional to:

- the square of the flow rate (Q)
- the gas specific gravity (s)
- the pipe length (l)

Pressure loss varies inversely with the fifth power of the pipe diameter (d).

If the quantity of gas is doubled, the pressure loss will increase 4 times, i.e. $(2)^2$.

If the pipe length is doubled, the pressure loss will double.

If the pipe diameter is halved, the pressure loss will increase 32 times, i.e. $(2)^5$.

Note: Pole's formula is limited to normal low pressure gas installations. Under higher pressure, alternative formulae which incorporate gas compressibility factors are more appropriate.

Typical natural gas consumption figures for domestic appliances:

Boiler	1·6 m^3/hour
Cooker	1·0 " "
Fire	0·5 " "

Exact gas consumption rate (Q) can be calculated from the following formula:

$$Q = \frac{\text{Appliance rating} \times 3600}{\text{Calorific value of gas}}$$

Given that the calorific values for natural gas and propane (LPG) are 38 500 kJ/m^3 and 96 000 kJ/m^3 respectively, the value of Q for a 20 kW input boiler is:

$$\text{Nat. gas}: Q = \frac{20 \times 3600}{38\,500} = 1{\cdot}87\ m^3/h$$

$$\text{Propane}: Q = \frac{20 \times 3600}{96\,000} = 0{\cdot}75\ m^3/h$$

Operating costs – fuel tariffs can be obtained from the various gas suppliers. A typical charge for natural gas is 1·3 pence per kWh. If the 20 kW input boiler consumes gas for 5 hours per day, the operating cost will be:

$$1{\cdot}3 \times 20 \times 5 = £1{\cdot}30 \text{ per day or } 9{\cdot}10 \text{ per week}$$

To convert gas metered in units of cubic feet, multiply by 0·0283, i.e. 1 cu. ft. = 0·0283 m^3.

Gas consumed in kWh:

$$\frac{m^3 \times \text{volume conversion factor } (1{\cdot}02264) \times \text{calorific value } (MJ/m^3)}{3{\cdot}6}$$

where: 1 kWh = 3·6 MJ.

e.g. 100 cu. ft at 2·83 m^3

$$\frac{2{\cdot}83 \times 1{\cdot}02264 \times 38{\cdot}5}{3{\cdot}6} = 31\ kWh$$

To determine the size of pipework, two factors must be established:

1. The gas consumption (Q).
2. The effective length of pipework.

Effective length of pipework is taken as the actual length plus the following allowances for fittings in installations up to 28 mm outside diameter copper tube:

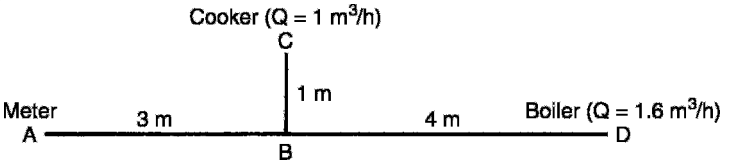
Fitting	Equivalent length (m)
elbow	0·5
tee	0·5
bend (90°)	0·3

The gas discharge in m^3/hour for copper tube for varying effective lengths is as follows:

Tube diam. (mm o.d)	Effective pipe length (m) 3	6	9	12	15	20	25	30
8	0·52	0·26	0·17	0·13	0·10	0·07		
10	0·86	0·57	0·50	0·37	0·30	0·22	0·18	0·15
12	1·50	1·00	0·85	0·82	0·69	0·52	0·41	0·34
15	2·90	1·90	1·50	1·30	1·10	0·95	0·92	0·88
22	8·70	5·80	4·60	3·90	3·40	2·90	2·50	2·30
28	18·00	12·00	9·40	8·00	7·00	5·90	5·20	4·70

This table is appropriate for 1 mb (10 mm w.g.) pressure drop for gas of relative density 0·6.

Example:



Note: A to B contains 3 elbows and 1 tee
B to C contains 3 elbows
B to D contains 4 elbows

Pipe A to B, gas flow = 1 m^3/h + 1·6 m^3/h = 2·6 m^3/h

Actual pipe length = 3 m

Effective pipe length = 3 + (3 × 0·5) + (1 × 0·5) = 5 m

From the table, a 22 mm o.d. copper tube can supply 2·6 m^3/h for up to 23·75 metres (by interpolating between 20 and 25 m).

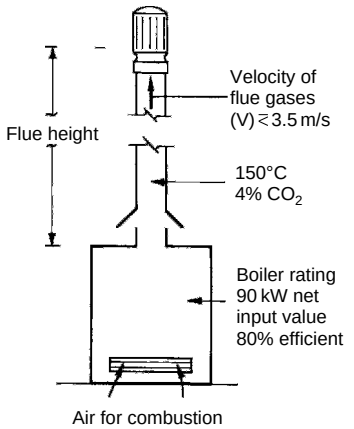
Pressure drop over only 5 m will be: 5 ÷ 23·75 = 0·21 mb (2·1 mm w.g.).

Pipes B to C and B to D can be calculated similarly.

Ref: BS 6891: Installation of low pressure gas pipework of up to 35 mm in domestic premises. Specification.

Open flue, naturally aspirated – a flue pipe equivalent to the size of the appliance outlet is generally adequate. However, some variation may be possible, but care must be taken not to undersize the flue, as this will cause a high efflux velocity and spillage of combustion products. Over-sizing is uneconomical, less easy to accommodate and likely to produce condensation in the flue.

Example:



Ambient temperature 20°C

Gross input value of boiler = 90 kW × $\frac{100}{80}$ = 112.50 kW

Calorific value of natural gas = 38 500 kJ/m^3

$$\text{Gas consumption rate (Q)} = \frac{\text{Appliance rating} \times 3600}{\text{Calorific value of gas}}$$

$$= \frac{112{\cdot}50 \times 3600}{38\,500} = 10{\cdot}52\ m^3/h$$

$$\text{Flue gas volume (v)} = \left[\frac{100}{\%\ CO_2} + 2\right] \times \text{Gas rate (Q)} \times \frac{^\circ C \text{ absolute} + ^\circ C \text{ flue gas}}{^\circ C \text{ absolute} + ^\circ C \text{ ambient}}$$

$$v = \left[\frac{100}{4} + 2\right] \times 10{\cdot}52 \times \frac{(273 + 150)}{(273 + 20)} = 410\ m^3/h$$

$$\text{Area of flue pipe (A)} = \frac{\text{Flue gas volume (v)}}{\text{Velocity of flue gas (V)}}$$

where, Flue gas volume (v) per second = 410 ÷ 3600 = 0·1139 m^3/s

$A = \frac{0{\cdot}1139}{3{\cdot}5} = 0{\cdot}0325\ m^2$ From, $A = \pi r^2$, radius(r) = 0·1018 m

Therefore, flue diameter = 0·203 m, or 203 mm (8" standard imperial size)

Induced draught flue – a conventional or open flue with a flue gas extract fan. Extract velocity (V) is between 6 and 7·5 m/s.

Using a 112·50 kW gross input rated boiler from the example on the previous page, the gas consumption rate (Q) and flue gas volume (v) are 10·52 m^3/h and 410 m^3/h respectively.

The flue pipe diameter formula is as shown on the previous page, but with the velocity of fanned flue gases (V) increased to say, 7 m/s.

$$A = \frac{v}{V} = \frac{0{\cdot}1139}{7} = 0{\cdot}0163\,m^2$$ From, $A = \pi r^2$, radius (r) = 0·0719 m

Therefore, flue diameter = 0·144 m, rounded up to 152 mm (6" standard imp. size)

Velocity check : $\frac{\text{Flue gas volume (v)}}{\text{Flue area (A)}} = \text{Flue gas velocity (V)}$

$$\frac{0{\cdot}1139}{\pi \times (0{\cdot}076)^2} = 6{\cdot}3\,m/s$$ Between 6 and 7·5 m/s, therefore 152 mm flue is satisfactory

Fan air diluted flue – see page 368 for installation between two side walls and for operating data. Using two of the 112·50 kW rated boilers with flue gas extract velocity (V) between 6 and 7 m/s, the following formula may be used to obtain the flue gas volume (v):

$$v = 9{\cdot}7 \times \text{Appliance rating} \times \frac{^\circ C \text{ absolute} + \text{flue gas } ^\circ C}{^\circ C \text{ absolute} + \text{ambient } ^\circ C}$$

$$v = 9{\cdot}7 \times 112{\cdot}50 \times 2 \times \frac{(273 + 50)}{(273 + 20)} = 2406\,m^3/h \text{ or, } 0{\cdot}6683\,m^3/s$$

$$A = \frac{v}{V} = \frac{0{\cdot}6683}{6} = 0{\cdot}1114\,m^2 \text{ flue area}$$

A square flue will be $\sqrt{0{\cdot}1114} = 334\,mm \times 334\,mm$

A circular flue is derived from Area(A) = πr^2 where, r = radius

Therefore, $r = \sqrt{A \div \pi}$

$r = \sqrt{0{\cdot}1114 \div 3{\cdot}1416} = 0{\cdot}188\,m$ or 188 mm

diameter of circular duct is 2 × r = 376 mm

The following formula is a guide to the minimum flue height (H) in metres, with regard to the efficient discharge of flue gases from naturally aspirated boilers:

$H = 6 \times (\text{Boiler rating gross input in MW})^{0.6}$ + allowance for resistances at bends, etc.

Factors for resistance to flue gas flow can be taken as listed below:

Flue pipe component	Resistance factor
90° bend	0·50
135° bend	0·25
Vertical terminal	0·25
Ridge terminal	1·00
Horizontal flue	0·30/m
Inclined flue (45°)	0·13/m
Vertical flue	zero

Taking the examples shown in the previous two pages of one 112·50 kW gross input (90 kW net) rated boiler. Assuming that the boiler flue is vertical with the exception of two 135° bends, one metre of 45° inclined flue and a vertical terminal, the formula for minimum flue height can be written:

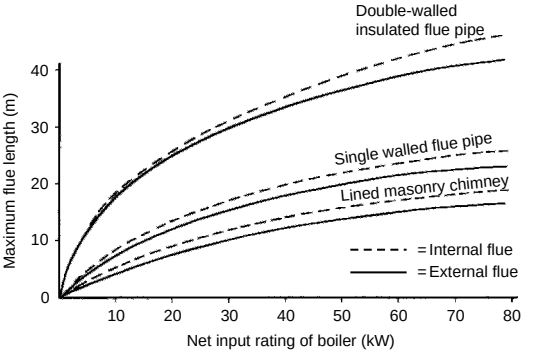
$$H = 6 \times (0{\cdot}1125)^{0.6} + (0{\cdot}25 \times 2) + (0{\cdot}13) + (0{\cdot}25) + 2{\cdot}4975, \text{ i.e. } 2{\cdot}5 \text{ m}$$

Condensation within a flue system must be prevented by:

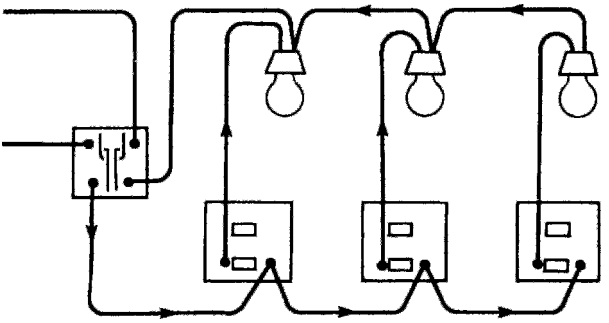
- keeping the flue gas temperature as high as possible
- keeping the dew point of the flue gases low

In practical terms this is achieved by:

- correctly sizing the flue to avoid excessive surface areas
- insulating the flue or use of double-walled, insulated flue pipes
- limiting the lengths of flue systems (see graph)



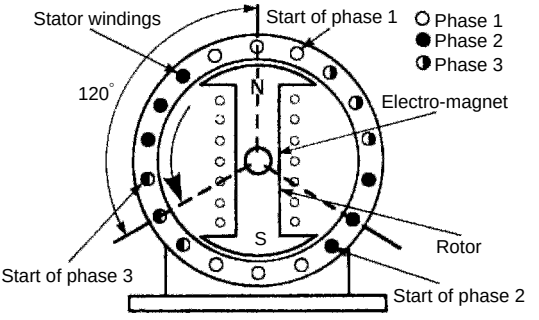
10 ELECTRICAL SUPPLY AND INSTALLATIONS



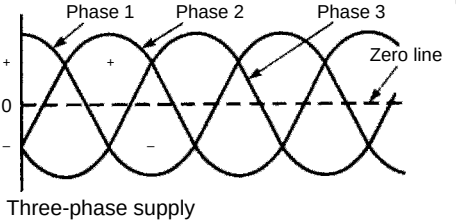
THREE-PHASE GENERATION AND SUPPLY
ELECTRICITY DISTRIBUTION
INTAKE TO A BUILDING
EARTHING SYSTEMS AND BONDING
CONSUMER UNIT
POWER AND LIGHTING CIRCUITS
OVERLOAD PROTECTION
ELECTRIC WIRING
TESTING COMPLETED INSTALLATION
CABLE RATING
DIVERSITY
DOMESTIC AND INDUSTRIAL INSTALLATIONS
ELECTRIC SPACE HEATING
SPACE HEATING CONTROLS
CONSTRUCTION SITE ELECTRICITY
LIGHT SOURCES, LAMPS AND LUMINAIRES
LIGHTING CONTROLS
EXTRA-LOW-VOLTAGE LIGHTING
LIGHTING DESIGN
DAYLIGHTING
TELECOMMUNICATIONS INSTALLATION

In 1831 Michael Faraday succeeded in producing electricity by plunging a bar magnet into a coil of wire. This is credited as being the elementary process by which we produce electricity today, but the coils of wire are cut by a magnetic field as the magnet rotates. These coils of wire (or stator windings) have an angular spacing of 120° and the voltages produced are out of phase by this angle for every revolution of the magnets. Thus generating a three-phase supply.

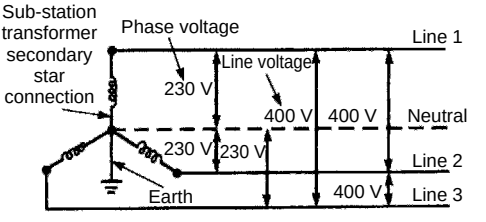
A three-phase supply provides 73% more power than a single-phase supply for the addition of a wire. With a three-phase supply, the voltage between two line or phase cables is 1·73 times that between the neutral and any one of the line cables, i.e. 230 volts × 173 = 400 volts, where 1·73 is derived from the square root of the three phases.



Simplified detail of three-phase generator or alternator



Three-phase supply



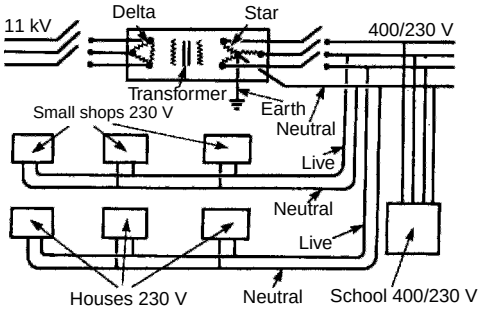
Relationship between line and phase voltage

Note: The following section on electrical systems should be read with regard to:

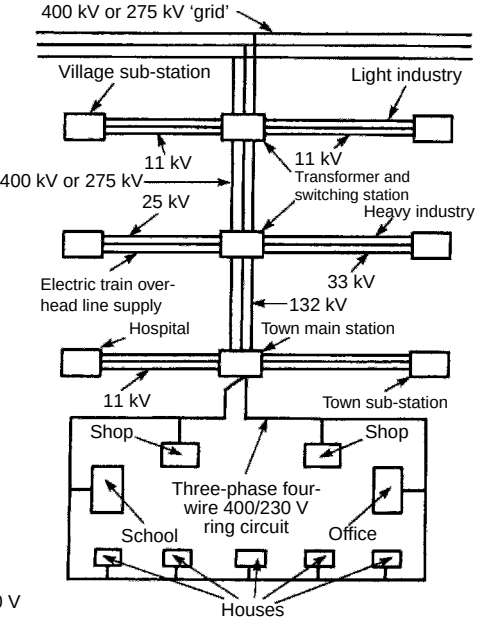
Building Regulations, Approved Document P: Electrical safety, and BS 7671: Requirements for Electrical Installations, the IEE Wiring Regulations 16th edition.

In the UK electricity is produced at power generating stations at 25 kilovolt (kV) potential, in three-phase supply at 50 cycles per second or hertz (Hz). Thereafter it is processed by step-up transformers to 132, 275 or 400 kV before connecting to the national grid. Power to large towns and cities is by overhead lines at 132 kV or 33 kV where it is transformed to an 11 kV underground supply to sub-stations. From these sub-stations the supply is again transformed to the lower potential of 400 volts, three-phase supply and 230 volts, single-phase supply for general distribution.

The supply to houses and other small buildings is by an underground ring circuit from local sub-stations. Supplies to factories and other large buildings or complexes are taken from the 132 or 33 kV main supply. Larger buildings and developments will require their own transformer, which normally features a delta-star connection to provide a four-wire, three-phase supply to the building.



Supply from town or village sub-station

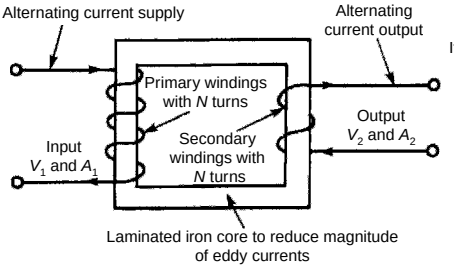


Supply to the buildings

Note: For easy identification, each phase cable has colour coded plastic insulation of brown (red), black (yellow) or grey (blue). The neutral is colour coded blue (black). An outer sheathing of red or black provides for future identification. Older installations will have colour codes as indicated in brackets.

A sub-station is required for the conversion, transformation and control of electrical power. It is used where large buildings or complexes of buildings require greater power than the standard low or medium potential of 230 and 400 volts. A sub-station must be constructed on the customer's premises. It is supplied by high voltage cables from the electricity authority's nearest switching station. The requirements for a sub-station depend upon the number and size of transformers and switchgear.

A transformer is basically two electric windings, magnetically interlinked by an iron core. An alternating electromotive force applied to one of the windings produces an electromagnetic induction corresponding to an electromotive force in the other winding.

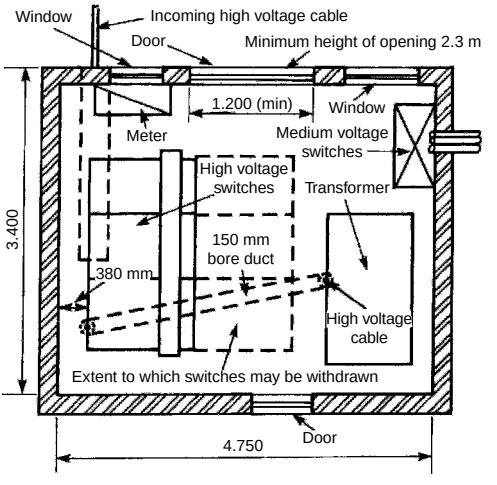


If losses are ignored, the following relationships of a transformer apply

$$\frac{V_1}{V_2} = \frac{N_1}{N_2} = \frac{I_2}{I_1}$$

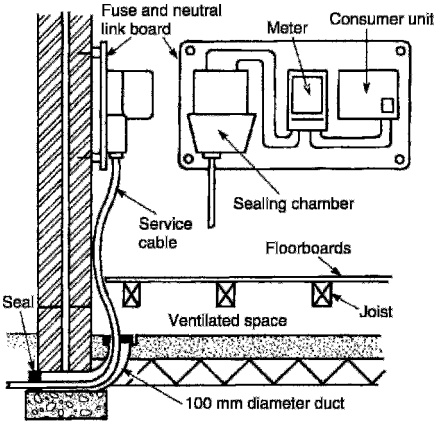
Where V_1 = primary voltage
V_2 = secondary voltage
N_1 = number of primary turns
N_2 = number of secondary turns
I_1 = primary current
I_2 = secondary current

Principle of transformer

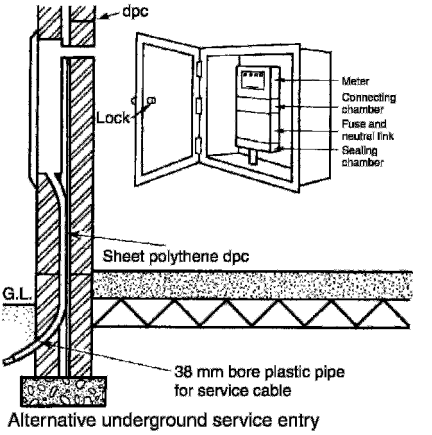


Construction and layout of sub-station

The termination and metering of services cables to buildings is determined by the electricity authority's supply arrangements. Most domestic supplies are underground with the service cable terminating at the meter cupboard, as shown. Depth of cover to underground cables should be at least 750 mm below roads and 450 mm below open ground. In remote areas the supply may be overhead. Whatever method is used, it is essential that a safety electrical earthing facility is provided and these are considered on the next page. All equipment up to and including the meter is the property and responsibility of the supplier. This also includes a fusible cut-out, neutral link and in some situations a transformer. Meters are preferably sited in a purpose-made reinforced plastic compartment set in or on the external wall of a building.



Underground service entry



Alternative underground service entry using external meter cabinet

Note: All domestic internal distribution systems must be undertaken by a `competent person', i.e. a qualified electrician. Electrical contractors certified as competent can `self-certificate' their work. Work completed by lesser qualified people must be referred to the Local Authority Building Control Department and a fee paid for inspection by their appointed qualified inspector. Minor work, such as replacing socket outlets, control switches and ceiling fittings can be undertaken without contravention.

Ref: Building Regulations, Approved Document P: Electrical Safety.

Supply systems require a safety electrical earthing facility. The manner in which this is effected will depend on whether the supply is overhead or underground and the conductive property of the ground surrounding the installation. Systems are classified in accordance with a letter coding:

First letter – type of earthing:

T – at least one point of the supply is directly earthed.

I – the supply is not directly earthed, but connected to earth through a current limiting impedance. Not acceptable for public supplies in the UK.

Second letter – installation earthing arrangement:

T – all exposed conductive metalwork is directly earthed.

N – all exposed conductive metalwork is connected to an earth provided by the supply company.

Third and fourth letters – earth conductor arrangement:

S – earth and neutral conductors separate.

C – earth and neutral conductors combined.

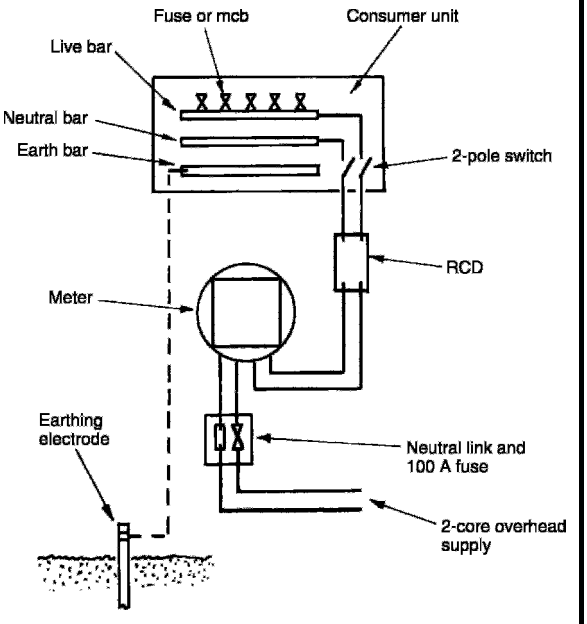
Common supply and earthing arrangements are:

TT (shown below).

TN-S and TN-C-S (shown next page).

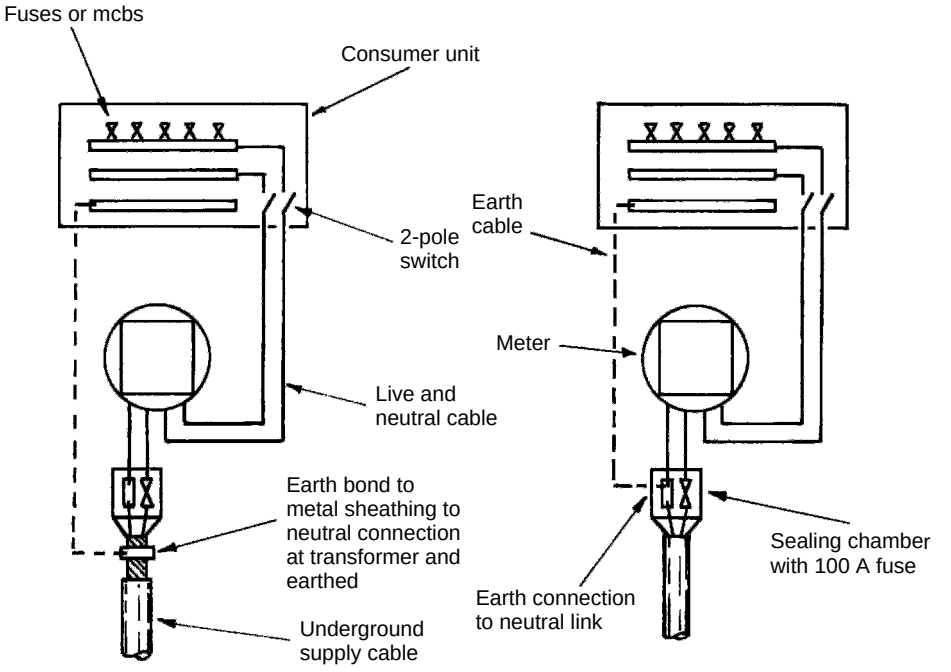
TT system:

Most used in rural areas where the supply is overhead. An earth terminal and electrode is provided on site by the consumer. As an extra safety feature, a residual current device (RCD), generally known as a trip switch, is located between the meter and consumer unit. The RCD in this situation should be of the time delayed type – see page 398.



TN-S system – this is widely used in the UK, with the electricity supply company providing an earth terminal with the intake cable. This is usually the metal sheathing around the cable, otherwise known as the supply protective conductor. It connects back to the star point at the area transformer, where it is effectively earthed.

TN-C-S system – this is as the TN-S system, but a common conductor is used for neutral and earth supply. The supply is therefore TN-C, but with a separated neutral and earth in the consumer's installation it becomes TN-C-S. This system is also known as protective multiple earth (PME). The advantage is that a fault to earth is also a fault to neutral, which creates a high fault current. This will operate the overload protection (fuse or circuit breaker) rapidly.

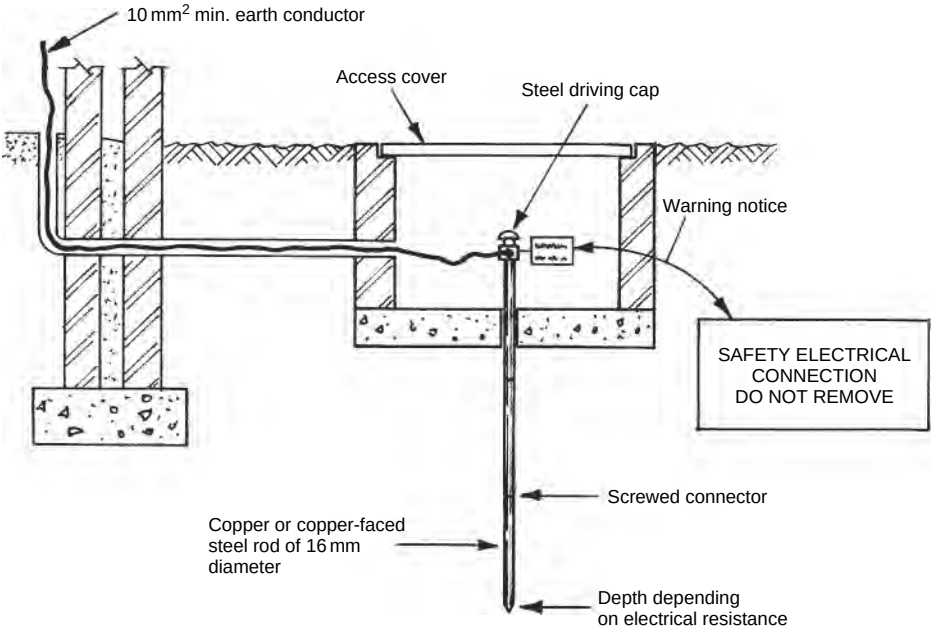


TN-S system TN-C-S system

Note: Specification of installation cable between supply company's sealing chamber and consumer's unit – phase/live and neutral 25 mm^2, earth 10 mm^2 cross-sectional area.

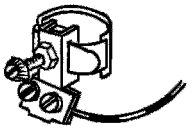
Pages 380, 381 and 385 show that the consumer's earth conductor is connected to the neutral and earthed at the local transformer. For below ground supplies this arrangement provides a path of low resistance for an electrical fault. With an overhead supply typical of rural areas, individual consumers must provide a suitable earth terminal or electrode as shown on page 384.

Unless wet, the ground surface is not usually a very good conductor, therefore ground contact is made at about 1·5 to 2 m below the surface. In the past this was achieved by earth bonding to metal water and gas mains. Since the introduction of plastic pipe materials, this is of course no longer acceptable. Current practices include burying a metal plate or a metal tape mesh arranged over several square metres, or driving a metal rod electrode into the ground. The latter is normally adequate for domestic and other small-scale installations. In some instances, the electrode is housed as shown below. Whatever earth method used, a low resistance to an electrical fault is essential. The IEE Wiring Regulations recommend that the earth electrode resistance should not exceed 200 ohms.

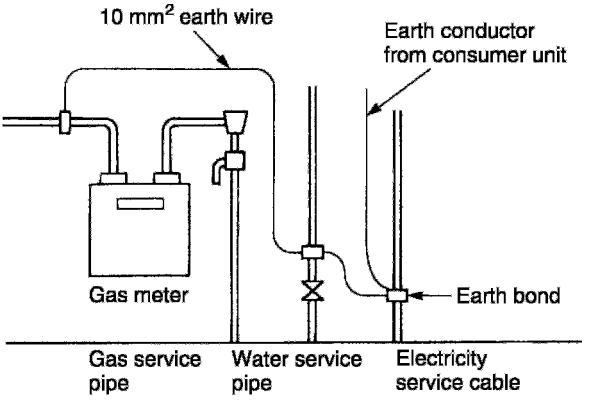


Installation of a housed earth electrode

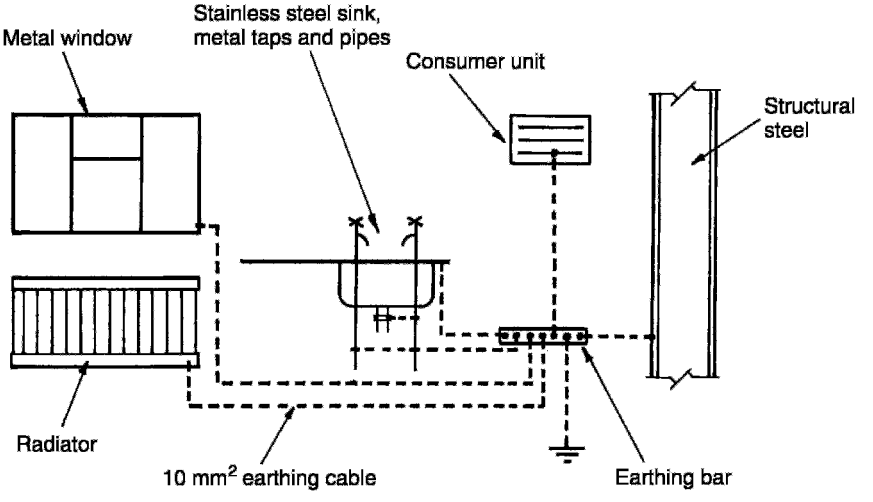
The Institution of Electrical Engineers (IEE) Wiring Regulations require the metal sheaths and armour of all cables operating at low and medium voltage to be cross-bonded to ensure the same potential as the electrical installation. This includes all metal trunking and ducts for the conveyance and support of electrical services and any other bare earth continuity conductors and metalwork used in conjunction with electrical appliances. The bonding of the services shall be as close as possible to the point of entry of the services into a building. Other fixed metalwork shall be supplementary earth bonded.



Earthing clamp for pipes



Bonding of services at intake



Supplementary bonding of extraneous metalwork

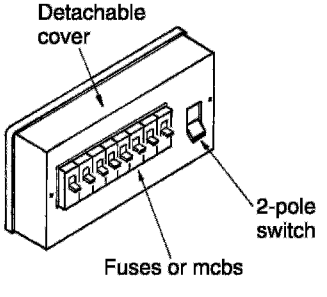
Historically, electrical installations required a separate fuse and isolator for each circuit. Modern practice is to rationalise this into one 'fuse box', known as a consumer's power supply control unit or consumer unit for short. This unit contains a two-pole switch isolator for the phase/live and neutral supply cables and three bars for the live, neutral and earth terminals. The live bar is provided with several fuse ways or miniature circuit breakers (up to 16 in number for domestic use) to protect individual circuits from overload. Each fuse or mcb is selected with a rating in accordance with its circuit function. Traditional fuses are rated at 5, 15, 20, 30 and 45 amps whilst the more modern mcbs are rated in accordance with BS EN 60898: Circuit breakers for over current protection for household and similar installations.

Circuit	Mcb rating (amps)
Lighting	6
Immersion heater	16 or 20*
Socket ring main	32
Cooker	40 or 45*
Shower	40 or 45*

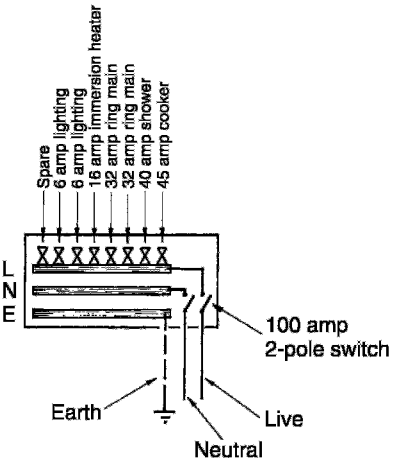
* Depends on the power rating of appliance. A suitable mcb can be calculated from: Amps = Watts ÷ Voltage.

E.g. A 3 kW immersion heater: Amps = 3000 ÷ 230 = 13.

Therefore a 16 amp rated mcb is adequate.



Eight-way consumer unit

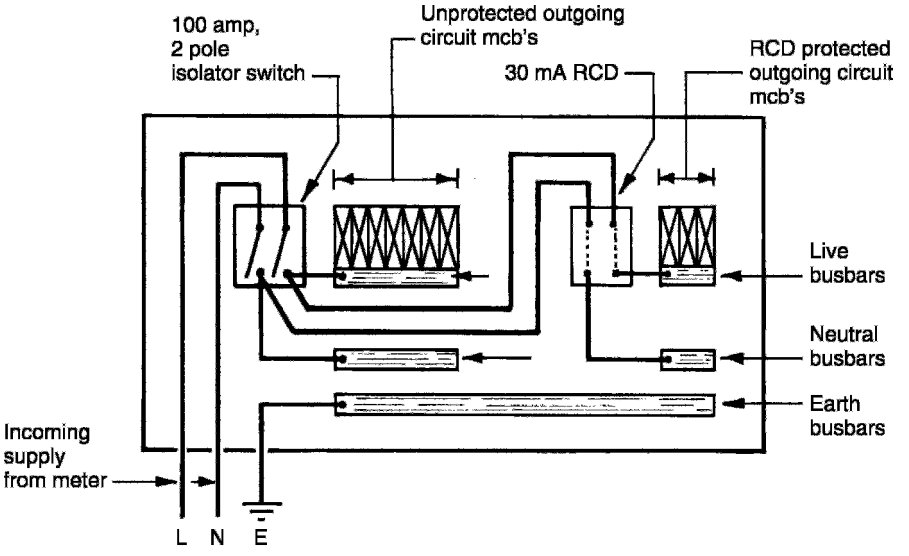


Typical contents of consumer unit

Refs: BS 5486-11 and 12, and BS EN 60439-3: Low-voltage switchgear and controlgear assemblies. Specifications.

A split load consumer unit provides for additional and specific protection to outgoing circuits that may supply electricity to portable equipment for use outdoors. This is particularly appropriate for ground floor sockets that could have an extension lead attached. For example, cooker control panel, kitchen ring main circuit and ground floor ring main circuit.

These ground floor circuits have a dedicated live and neutral bar within the consumer unit and an RCD (RCCB) protection device in addition to miniature circuit breakers for each individual circuit. A typical disposition of components within a split load consumer unit is as shown.



Contents of a split load consumer unit

Types of protection against residual current by residual current devices (RCDs):

- RCCB – Residual current circuit breaker. An incoming switch disconnecting device activated by an earth leakage fault – see page 398.
- RCBO – Residual current circuit breaker with integral overload protection. An alternative to a miniature circuit breaker (mcb) as an outgoing individual circuit protection device. It has a dual function, combining earth leakage protection with the current overload protection provided by an mcb.

Ring Circuit

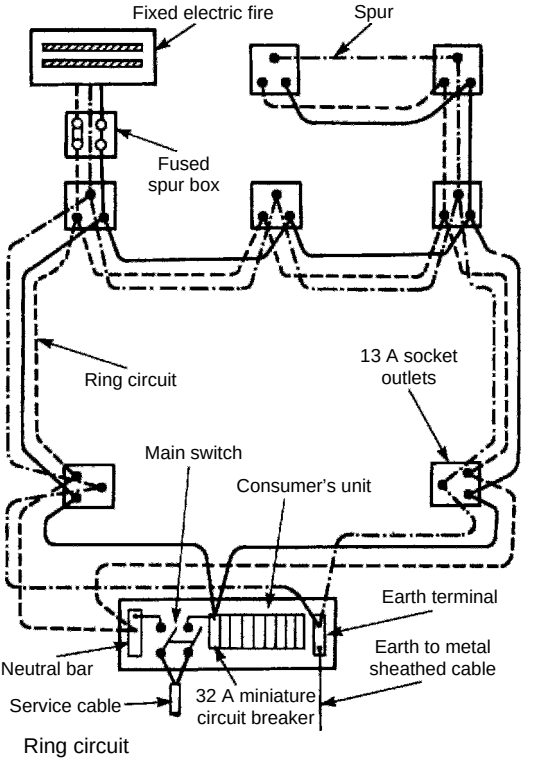
A ring circuit is used for single-phase power supply to three-pin sockets. It consists of PVC sheathed cable containing live and neutral conductors in PVC insulation and an exposed earth looped into each socket outlet. In a domestic building a ring circuit may serve an unlimited number of sockets up to a maximum floor area of 100 m^2. A separate circuit is also provided solely for the kitchen, as this contains relatively high rated appliances. Plug connections to the ring have small cartridge fuses up to 13 amp rating to suit the appliance wired to the plug. The number of socket outlets from a spur should not exceed the number of socket outlets and fixed appliances on the ring.

Cable rating:
2·5 mm^2 c.s.a.

Consumer unit:
BS 5486-13 and
BS EN 60439-1.

3-pin plugs and
sockets: BS 1363-1 and 2.

Plug cartridge
fuses: BS 1362.



Ring circuit

Note: Fixed appliances such as fires, heating controls and low powered water heaters can be connected to a fused spur from a ring socket. Appliances and installations with a load factor above 3 kW, e.g. immersion heater, cooker, extension to an outbuilding, etc. must not be connected to any part of a ring circuit. These are supplied from a separate radial circuit from the consumer unit.

Power sockets should be positioned between 150 mm and 250 mm above floor levels and work surfaces. An exception is in buildings designed for the elderly or infirm, where socket heights should be between 750 and 900 mm above the floor. Every socket terminal should be fitted with a double outlet to reduce the need for adaptors. Disposition of sockets would limit the need for lead lengths to no more than 2 m.

The following provides guidance on the minimum provision for power sockets in domestic accommodation:

Location	Minimum quantity of sockets
Living rooms	8
Kitchen	6
Master bedroom	6
Dining room	4
Study bedroom	4
Utility room	4
Single bedrooms	4
Hall and landing	2
Garage/workshop	2
Bathroom	1 – double insulated shaver socket

Maximum appliance load (watts) and plug cartridge fuse (BS 1362) selection for 230 volt supply:

Maximum load (W)	Plug fuse rating (amp)
230	1
460	2
690	3
1150	5
1610	7
2300	10
2900	13

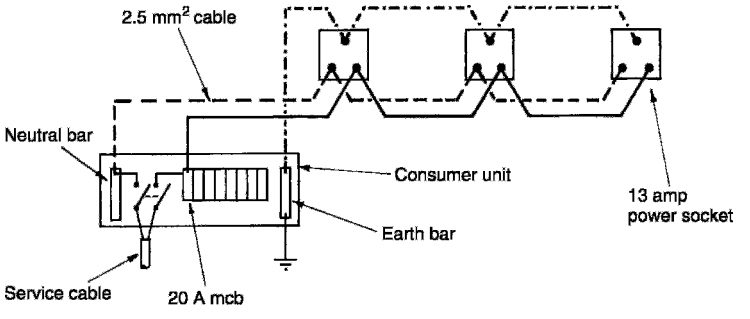
Calculated from: Watts = Amps × Voltage.

A radial circuit may be used as an alternative to a ring circuit to supply any number of power sockets, provided the following limitations are effected:

Cable c.s.a. (mm^2)	Minimum overload protection (amps)	Remarks
2.5	20	Max. 20 m^2 floor area, 17 m cable
4.0	30	Max. 50 m^2 floor area, 21 m cable

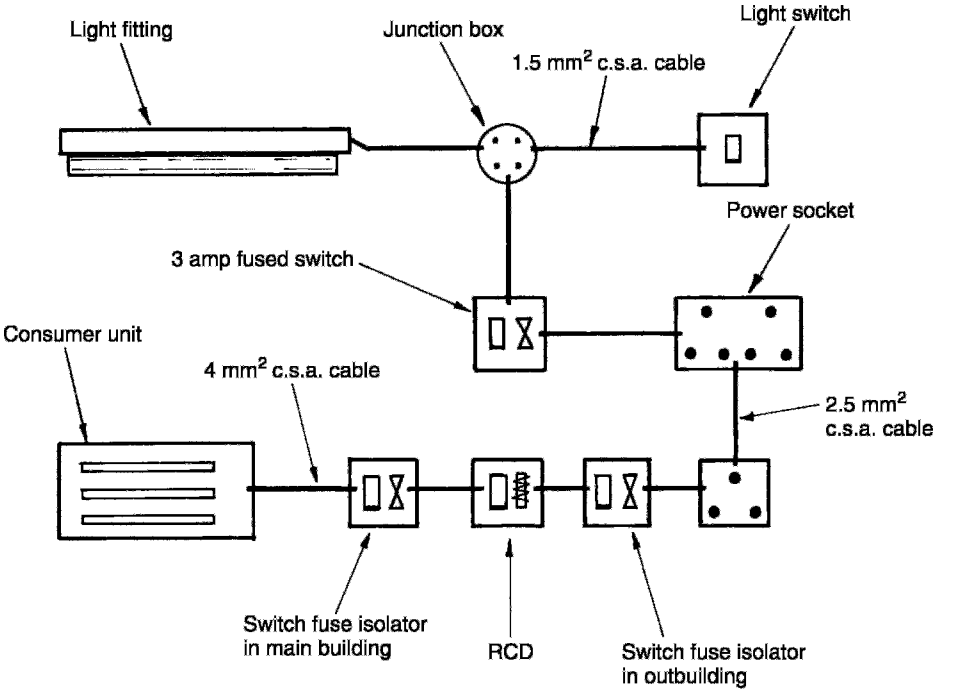
With 2·5 mm^2 cable length limitation of 17 m over 20 m^2 floor area for a radial supply to sockets, a ring main with a maximum cable length of 54 m over 100 m^2 will usually prove to be more effective. Therefore radial circuits are more suited to the following:

Application	Cable c.s.a. (mm^2)	Minimum overload protection (amps)	Remarks
Lighting	1·5	5	Max. 10 light fittings
Immersion heater	2·5	15	Butyl rubber flex from 2-pole control switch
Cooker	6	30	Cable and fuse ratings to suit cooker rating
	10	45	
Shower	4, 6 or 10	30 to 45	See page 286
Storage radiator	2·5	20	See page 410
Outside extension	2·5	20	Nominal light and power
	4	30	Max. five sockets and 3 amp light circuit (next page)



Radial circuit to power sockets

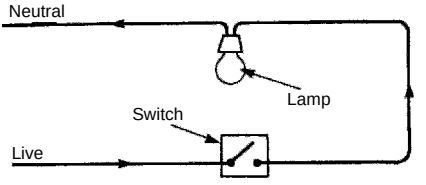
An electricity supply to an outside building may be overhead at a height not less than 3·5 m. It may be supported in a conduit or from a catenary suspension wire. An underground supply is less obtrusive and should be at least 500 mm below the surface. The cable should be armoured PVC sheathed or copper sheathed mineral insulated (MICC). Standard PVC insulated cable may be used, provided it is enclosed in a protective conduit. Fused isolators are required in the supply building and the outside building, and a residual current device (RCD) 'trip switch' should also be installed after the fused switch control from the consumer unit. Two-point-five mm^2 c.s.a. cable is adequate for limited installations containing no more than a power socket and lighting. In excess of this, a 4 mm^2 c.s.a. cable is preferred particularly if the outbuilding is some distance to overcome the voltage drop.



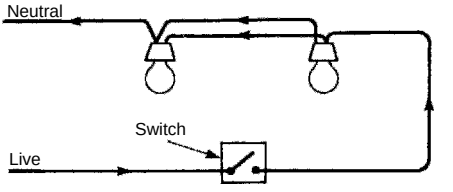
Schematic diagram of electricity supply to an outbuilding

Lighting circuits can incorporate various switching arrangements. In a one-way switch circuit the single-pole switch must be connected to the live conductor. To ensure that both live and neutral conductors are isolated from the supply a double-pole switch may be used, although these are generally limited to installations in larger buildings where the number and type of light fittings demand a relatively high current flow. Provided the voltage drop (4% max., see page 404) is not exceeded, two or more lamps may be controlled by a one-way single-pole switch.

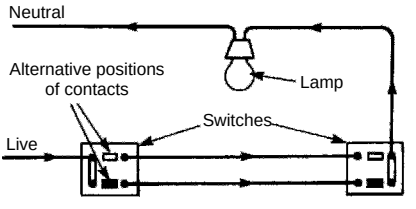
In principle, the two-way switch is a single-pole changeover switch interconnected in pairs. Two switches provide control of one or more lamps from two positions, such as that found in stair/landing, bedroom and corridor situations. In large buildings, every access point should have its own lighting control switch. Any number of these may be incorporated into a two-way switch circuit. These additional controls are known as intermediate switches.



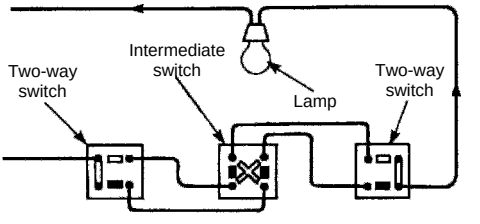
One-way single-pole switch circuit controlling one lamp.



One-way single-pole switch circuit controlling two or more lamps

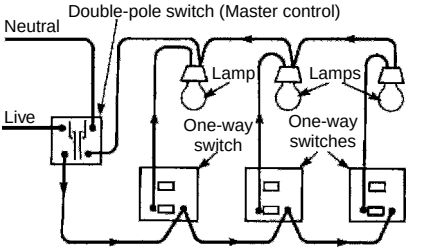


Two-way switching



Two-way switching with one intermediate switch

The purpose of a `master' switch is to limit or vary the scope of control afforded by other switches in the same circuit. If a `master' switch (possibly one with a detachable key option) is fixed near the main door of a house or flat, the householder is provided with a means of controlling all the lights from one position.



'Master' control wiring circuit

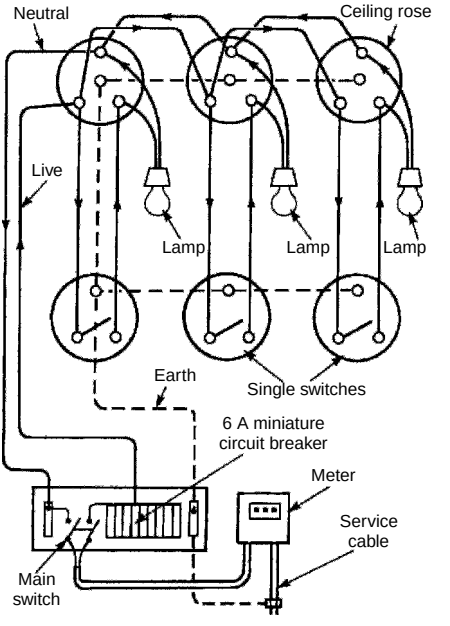
A sub-circuit for lighting is generally limited to a total load of 10, 100 watt light fittings. It requires a 5 amp fuse or 6 amp mcb overload protection at the consumer unit. The importance of not exceeding these ratings can be seen from the simple relationship between current (amps), power (watts) and potential (voltage), i.e. Amps = Watts ÷ Volts. To avoid overloading the fuse or mcb, the limit of 10 lamps @ 100 watts becomes:

Amps = (10 × 100) ÷ 230 = 4·3

i.e. <5 amps fuse protection.

In large buildings higher rated overload protection is often used due to the greater load.

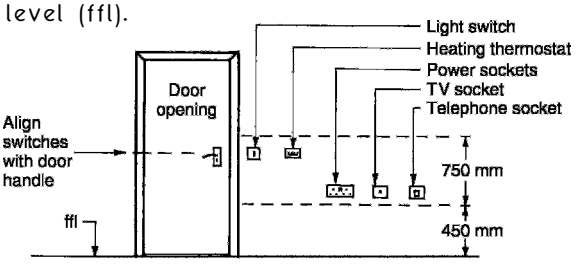
Wiring for lighting is usually undertaken using the `looping-in' system, although it is possible to use junction boxes instead of ceiling roses for connections to switches and light fittings.



Looping-in system of wiring

The Building Regulations require reasonable provision for people, whether ambulant or confined to a wheelchair, to be able to use a building and its facilities. Facilities include wall-mounted switches and sockets located within easy reach, to be easily operated, visible and free of obstruction.

Dwellings – switches and sockets between 450 and 1200 mm from finished floor level (ffl).



Location of switches and sockets in a dwelling

Non-domestic buildings – basic requirements for switches, outlets and controls:

- Conventional and familiar.
- Contrasting in colour to their surroundings.
- Large push pad preferred or extra wide rocker switches.
- Pictogram to clarify use and purpose where multiple switches occur.
- Separation or gap between individual switches where multiples exist.

Recommendations for location of wall-mounted switches and sockets in non-domestic buildings:

- Sockets for TV, power and telephone: 400 to 1000 mm above ffl and ⩾350 mm from corners. Power socket switches to indicate whether they are 'ON'.
- Switches to permanently wired appliances: 400 to 1200 mm above ffl.
- Controls requiring precise hand movement: 750 to 1200 mm above ffl.
- Push buttons, e.g. lift controls; ⩽1200 mm above ffl.
- Pull cords for emergencies, coloured red and located close to a wall and to have 2, 50 mm diameter bangles set 100 mm and 800–900 mm above ffl.
- Controls that require close visual perception, e.g. thermostat, located 1200–1400 mm above ffl for convenience of people sitting or standing.
- Light switches for general use of the push pad type and located at 900–1100 mm height. Alternatively, a pull cord with 50 mm diameter bangle set at the same height. The pull cord should be distinguishable from any emergency pull.
- Main and circuit isolators to clearly indicate that they are 'ON' or 'OFF'.
- Pattress or front plate to visually contrast with background.
- Operation of switches and controls to be from one hand, unless both hands are required for safety reasons.

Note: Exceptions to the above may occur in unavoidable design situations such as open plan offices with fitted floor sockets.

Refs: Building Regulations, Approved Document M: Access to and use of buildings. Disability Discrimination Act.
BS 8300: Design of buildings and their approaches to meet the needs of disabled people – Code of Practice.

Electrical installations must be protected from current overload, otherwise appliances, cables and people using the equipment could be damaged. Protection devices can be considered in three categories:

1. Semi-enclosed (rewirable) fuses.
2. High breaking or rupturing capacity (HBC or HRC) cartridge fuses.
3. Miniature circuit breakers (mcb).

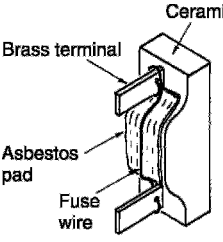
None of these devices necessarily operate instantly. Their efficiency depends on the degree of overload. Rewirable fuses can have a fusing factor of up to twice their current rating and cartridge fuses up to about 1·6. Mcbs can carry some overload, but will be instantaneous (0·01 seconds) at very high currents.

Characteristics:

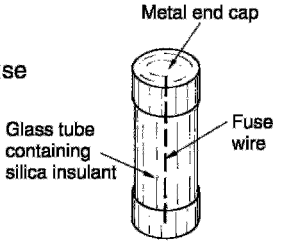
Semi-enclosed rewirable fuse:
Inexpensive.
Simple, i.e. no moving parts.
Prone to abuse (wrong wire could be used).
Age deterioration.
Unreliable with temperature variations.
Cannot be tested.

Cartridge fuse:
Compact.
Fairly inexpensive, but cost more than rewirable.
No moving parts.
Not repairable.
Could be abused.

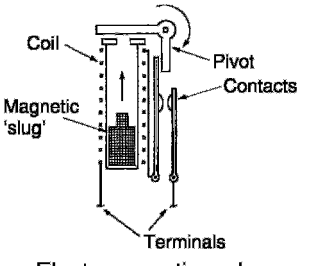
Miniature circuit breaker:
Relatively expensive.
Factory tested.
Instantaneous in high current flow.
Unlikely to be misused.



Rewirable fuse



Cartridge fuse



Electomagnetic mcb

Refs: BS 88-5 and 6: Cartridge fuses for voltages up to and including 1000 V a.c. and 1500 V d.c.
BS 1361: Specification for cartridge fuses for a.c. circuits in domestic and similar premises.
BS EN 60269: Low voltage fuses.
BS EN 60898: Circuit breakers for overcurrent protection for household and similar installations.

Residual Current Devices (RCD) are required where a fault to earth may not produce sufficient current to operate an overload protection device (fuse or mcb), e.g. an overhead supply. If the impedance of the earth fault is too high to enable enough current to effect the overload protection, it is possible that current flowing to earth may generate enough heat to start a fire. Also, the metalwork affected may have a high potential relative to earth and if touched could produce a severe shock.

An RCD has the load current supplied through two equal and opposing coils, wound on a common transformer core. When the live and neutral currents are balanced (as they should be in a normal circuit), they produce equal and opposing fluxes in the transformer or magnetic coil. This means that no electromotive force is generated in the fault detector coil. If an earth fault occurs, more current flows in the live coil than the neutral and an alternating magnetic flux is produced to induce an electromotive force in the fault detector coil. The current generated in this coil activates a circuit breaker.

Whilst a complete system can be protected by a 100 mA (milliamp) RCD, it is possible to fit specially equipped sockets with a 30 mA RCD where these are intended for use with outside equipment. Plug-in RCDs are also available for this purpose. Where both are installed it is important that discrimination comes into effect. Lack of discrimination could effect both circuit breakers simultaneously, isolating the whole system unnecessarily. Therefore the device with the larger operating current should be specified with a time delay mechanism.

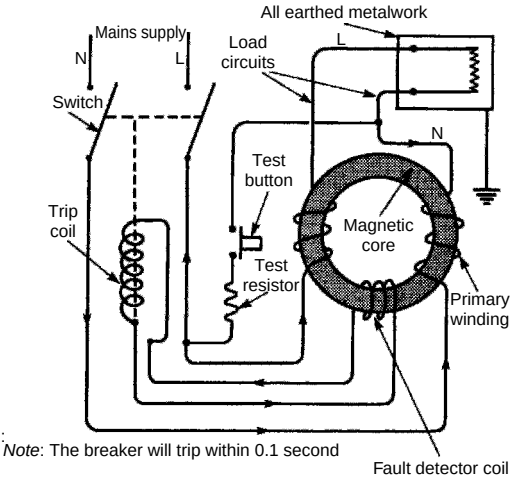
The test resistor provides extra current to effect the circuit breaker. This should be operated periodically to ensure that the mechanics of the circuit breaker have not become ineffective due to dirt or age deterioration. A notice to this effect is attached to the RCD.

Ref: BS ENs 61008 and 61009: Residual current operated circuit breakers.

An RCD is not appropriate for use with a TN-C system, i.e. combined neutral and earth used for the supply, as there will be no residual current when an earth fault occurs as there is no separate earth pathway.

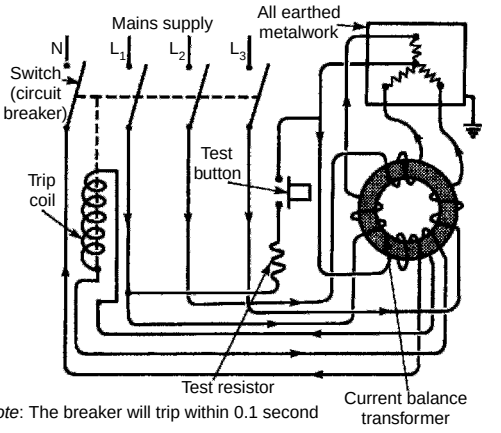
They are used primarily in the following situations:

- Where the electricity supply company do not provide an earth terminal, e.g. a TT overhead supply system.
- In bedrooms containing a shower cubicle.
- For socket outlets supplying outdoor portable equipment.



Note: The breaker will trip within 0.1 second

Single-phase RCD

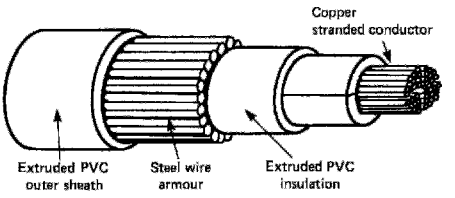


Note: The breaker will trip within 0.1 second

Three-phase RCD

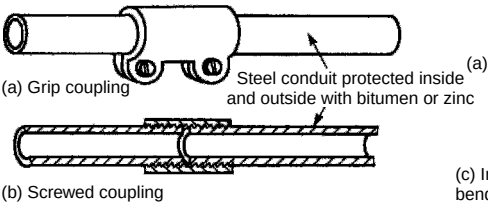
A three-phase device operates on the same principle as a single-phase RCD, but with three equal and opposing coils.

Armoured cable is used for mains and sub-mains. The cable is laid below ground level, breaking the surface where it enters sub-stations or transformers and other buildings. High voltage cable is protected below ground by precast concrete 'tiles'.

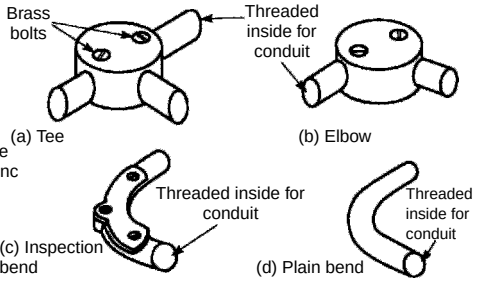


Armoured three-phase four wire cable for laying below ground level

Conduit for electrical services is produced in steel (galvanised or painted black) or plastic tube into which insulated cables are drawn. The conduit protects the cable from physical damage and heat. It also provides continuous support and if it is metal, it may be used as an earth conductor. Standard outside diameters are 20, 25, 32 and 40 mm. Steel is produced in either light or heavy gauge. Light gauge is connected by grip fittings, whilst the thicker walled heavy gauge can be screw threaded to fittings and couplings. Plastic conduit has push-fit connections.



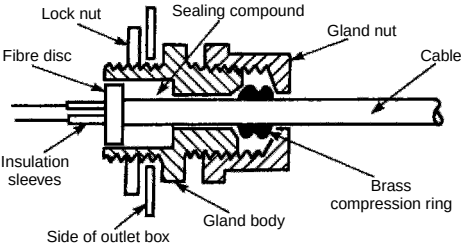
Couplings for steel conduit



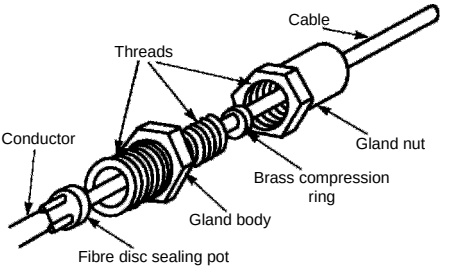
Fittings for steel conduit

Refs: BS 6346: Electric cables. PVC insulated, armoured cables for voltages of 600/1000 V and 1900/3300 V.
BS EN 61386: Conduit systems for cable management.
BS 7846: Electric cables. 600/1000 V armoured fire resistant cables having thermosetting insulation and low emission of smoke and gases when affected by fire.

Mineral insulated copper covered cable (MICC) has copper conductors insulated with highly compressed magnesium oxide powder inside a copper tube. When installing the cable, it is essential that the hygroscopic insulant does not come into contact with a damp atmosphere. Cutting the cable involves special procedures which are used to seal the insulant from penetration of atmospheric dampness. The cable provides an excellent earth conductor; it is also resistant to most corrosive atmospheres and is unaffected by extremes of heat.

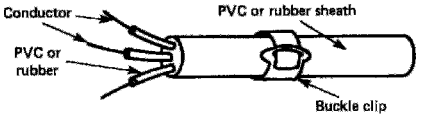


Section of termination joint for mineral insulated copper covered cable (MICC)

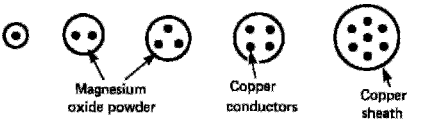


Exploded view of termination joint for mineral insulated copper covered cable

PVC and rubber insulated cables are relatively inexpensive and simple to install, requiring clipped support at regular intervals. PVC cables are in general use, but they have a temperature limitation between 0°C and 70°C. Below zero they become brittle and are easily damaged and at the higher temperature they become soft, which could encourage the conductor to migrate through the PVC. Outside of these temperatures, the cable must be protected or an appropriate rubber insulant specified. Cables usually contain one, two or three conductors. In three-core cable the live and neutral are insulated with brown and blue colour coding respectively. The earth is bare and must be protected with green and yellow sleeving where exposed at junction boxes, sockets, etc. Grey and black insulated conductors are occasionally used where an additional facility is required, e.g. two-way lighting.



PVC or rubber insulated cable



Core arrangements of mineral insulated copper covered cables

Refs: BS 6004 Electric cables. PVC insulated, non-armoured cables for voltages up to and including 450/750 V, for electric power, lighting and internal wiring.
BS 6007: Electric cables. Single core unsheathed heat resisting cables for voltages up to and including 450/750 V, for internal wiring.

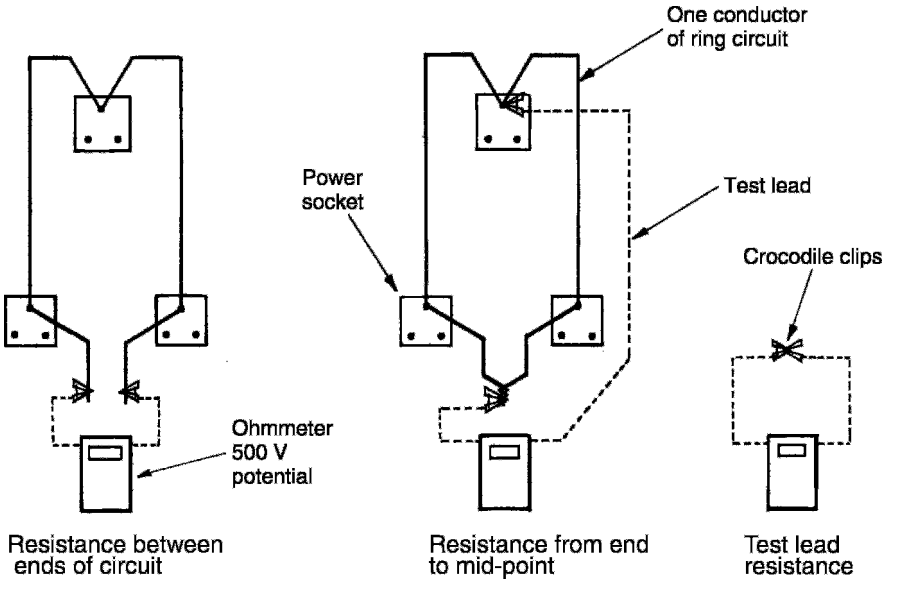
Electrical installations must be tested on completion to verify that the system will operate efficiently and safely. The tests are extensive, as defined in the Institution of Electrical Engineers Regulations. They can only be carried out by a competent person, i.e. a qualified electrician or electrical engineer. The following tests are an essential part of the proceedings:

- Continuity.
- Insulation.
- Polarity.

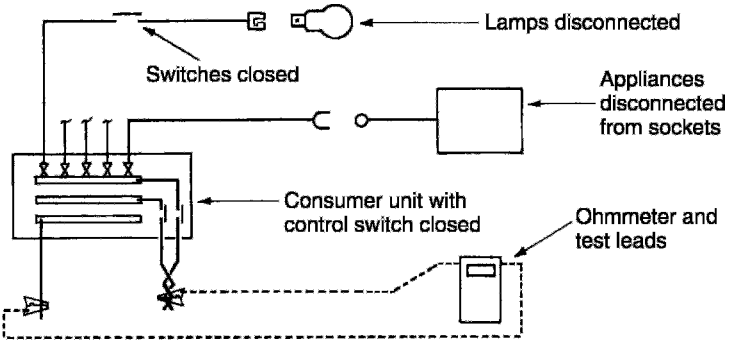
Testing is undertaken by visual inspection and the use of a multi-purpose meter (multimeter) or an instrument specifically for recording resistance, i.e. an ohmmeter.

Continuity – there are several types of continuity test for ring mains. Each is to ensure integrity of the live, neutral and earth conductors without bridging (shorting out) of connections. The following is one established test to be applied to each conductor:

- Record the resistance between the ends of the ring circuit (A).
- Record the resistance between closed ends of the circuit and a point mid-way in the circuit (B).
- Check the resistance of the test lead (C).
- Circuit integrity is indicated by: A ÷ 4 approx. = B – C.

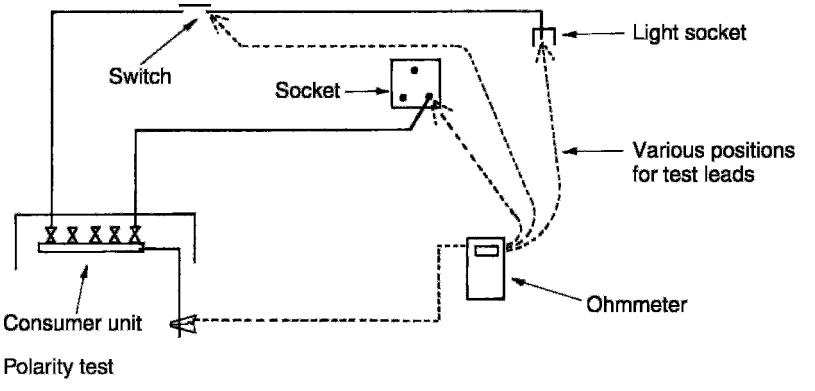


Insulation – this test is to ensure that there is a high resistance between live and neutral conductors and these conductors and earth. A low resistance will result in current leakage and energy waste which could deteriorate the insulation and be a potential fire hazard. The test to earth requires all lamps and other equipment to be disconnected, all switches and circuit breakers closed and fuses left in. Ohmmeter readings should be at least 1 MΩ.



Insulation test

Polarity – this is to ensure that all switches and circuit breakers are connected in the phase or live conductor. An inadvertant connection of switchgear to a neutral conductor would lead to a very dangerous situation where apparent isolation of equipment would still leave it live! The test leads connect the live bar in the disconnected consumer unit to live terminals at switches. A very low resistance reading indicates the polarity is correct and operation of the switches will give a fluctuation on the ohmmeter.



Polarity test

Ref: BS EN 61010-1: Safety requirements for electrical equipment for measurement, control and laboratory use.

Standard applications	Cable specification (mm^2 c.s.a.)
Lighting	1 or 1·5
Immersion heater	1·5 or 2·5
Sockets (ring)	2·5
Sockets (radial)	2·5 or 4 (see page 392)
Cooker	6 or 10
Shower	4, 6 or 10 (see page 286)

Some variations occur as the specification will depend on the appliance or circuit loading – see calculation below. Where non-standard circuits or special installations are necessary, the cable specification must be calculated in the following stages:

- Determine the current flowing.
- Select an appropriate cable (see table below).
- Check that the voltage drop is not greater than 4%.

Current ratings and voltage reduction for PVC insulated cables:

c.s.a. (mm^2)	Current carrying capacity (amps)		Voltage drop (mV/amp/m)
	In conduit	Clipped	
1	13·5	15·5	44
1·5	17·5	20	29
2·5	24	27	18
4	32	37	11
6	41	47	7·3
10	57	65	4·4

E.g. a 7.2 kW shower with a cable length of 10 m in conduit:

Amps = Watts ÷ Volts = 7200 ÷ 230 = 31·3
From table, select 4 mm^2 c.s.a. (32 amps)

Voltage drop = (mV × Current flowing × Cable length) ÷ 1000
= (11 × 31·3 × 10) ÷ 1000 = 3·44 volts

Maximum voltage drop = 230 × 4% = 9·2 volts.
Therefore, 4 mm^2 c.s.a. cable is satisfactory.

Note: Correction factors may need to be applied, e.g., when cables are grouped, insulated or in an unusual temperature. The IEE regulations should be consulted to determine where corrections are necessary.

Diversity in electrical installations permits specification of cables and overload protection devices with regard to a sensible assessment of the maximum likely demand on a circuit. For instance, a ring circuit is protected by a 30 amp fuse or 32 amp mcb, although every socket is rated at 13 amps. Therefore if only three sockets were used at full rating, the fuse/mcb would be overloaded. In practice this does not occur, so some diversity can be incorporated into calculations.

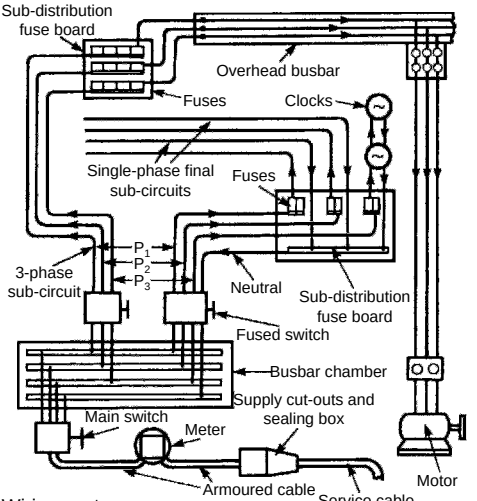
Guidance for diversity in domestic installations:

Circuit	Diversity factor
Lighting	66% of the total current demand.
Power sockets	100% of the largest circuit full load current + 40% of the remainder.
Cooker	10 amps + 30% full load + 5 amps if a socket outlet is provided.
Immersion heater	100%.
Shower	100% of highest rated + 100% of second highest + 25% of any remaining.
Storage radiators	100%.

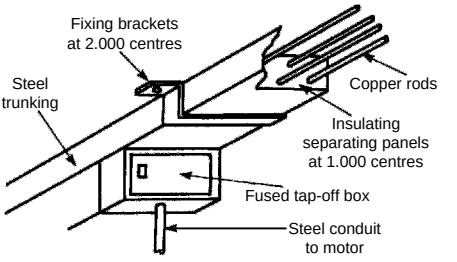
E.g. a house with 7·2 kW shower, 3 kW immersion heater, three ring circuits and three lighting circuits of 800 W each:

Appliance/circuit	Current demand (amps)	Diversity allowance (amps)
Shower	$\frac{7200}{230} = 31{\cdot}3$	31·3 × 100% = 31·3
Ring circuit-1	30	30 × 100% = 30
Ring circuit-2	30	30 × 40% = 12
Ring circuit-3	30	30 × 40% = 12
Lighting	$3 \times 800 = \frac{2400}{230} = 10{\cdot}4$	10·4 × 66% = 6·9
		Total = 92·2 amps

For a factory of modest size where the electrical load is not too high, a three-phase, four-wire, 400 volts supply will be sufficient. The distribution to three-phase motors is through exposed copper busbars in steel trunking running around the periphery of the building. Supply to individual motors is through steel conduit via push button switchgear. In addition to providing protection and support, the trunking and conduit can be used as earth continuity.



Wiring system



Detail of overhead busbar

Switches must be within easy reach of machinery operators and contain a device to prevent restarting of the motor after a power failure stoppage.

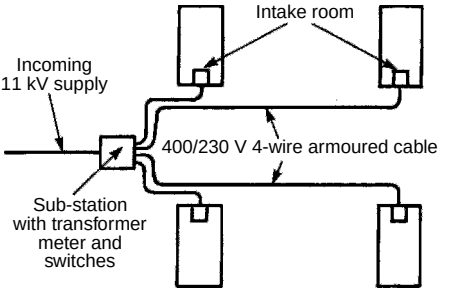
Overhead busbars provide an easily accessible means of connecting supplies to machinery by bolting the cable to the busbars.

Lighting and other single-phase circuits are supplied through separate distribution fuse boards.

Refs: BS EN 60439-1: Specification for low-voltage switchgear and control assemblies.
BS EN 60439-2: Particular requirements for busbar trunking systems (busways).

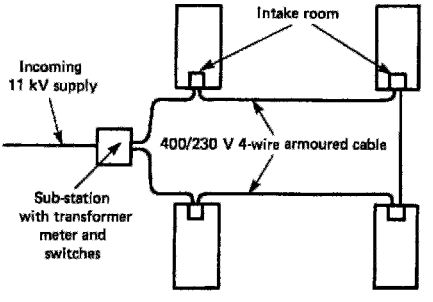
For large developments containing several buildings, either radial or ring distribution systems may be used.

Radial system – separate underground cables are laid from the sub-station to each building. The system uses more cable than the ring system, but only one fused switch is required below the distribution boards in each building.

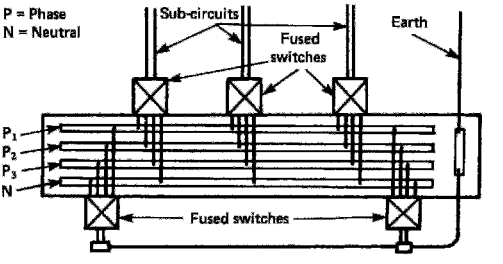


Radial distribution (block plan)

Ring circuit system – an underground cable is laid from the sub-station to loop in to each building. To isolate the supply, two fused switches are required below the distribution boards in each building. Current flows in both directions from the intake, to provide a better balance than the radial system. If the cable on the ring is damaged at any point, it can be isolated for repair without loss of supply to any of the buildings.



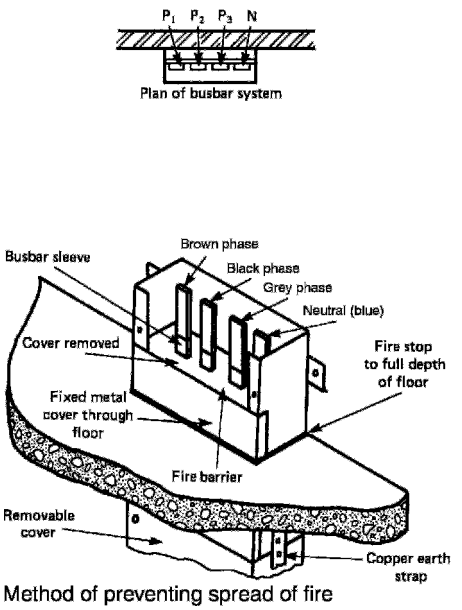
Ring distribution (block plan)



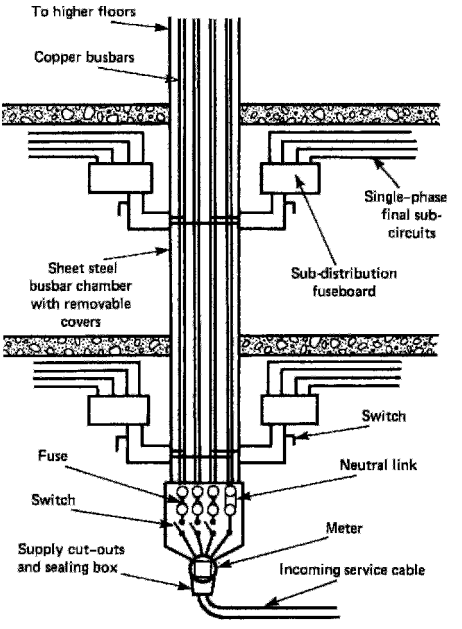
Detail of equipment in the intake room for the ring distribution

The rising main supply system is used in high rise offices and flats. Copper busbars run vertically inside trunking and are given support by insulated bars across the trunking chamber. The supply to each floor is connected to the rising main by means of tap-off units. To balance electrical distribution across the phases, connections at each floor should be spread between the phase bars. If a six-storey building has the same loading on each floor, two floors would be supplied from separate phases. Flats and apartments will require a meter at each tap-off unit.

To prevent the spread of fire and smoke, fire barriers are incorporated with the busbar chamber at each compartment floor level. The chamber must also be fire stopped to the full depth of the floor.



Method of preventing spread of fire



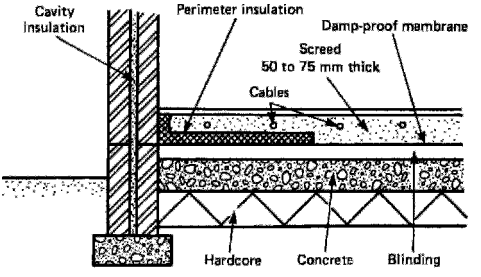
Detail of rising main system

Ref: Building Regulations, Approved Document B3: Internal fire spread (structure).

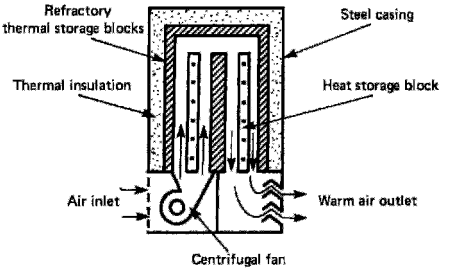
It is uneconomic to shut down electricity generating plant over night, even though there is considerably less demand. To encourage the use of off-peak energy, the electricity supply companies offer it at an inexpensive tariff. A timer and white meter or economy 7 (midnight to 0700) meter controls the supply to an energy storage facility.

Underfloor – makes use of the thermal storage properties of a concrete floor. High resisting insulated conductors are embedded in the floor screed at 100 to 200 mm spacing, depending on the desired output. This is about 10 to 20 W/m of cable. To be fully effective the underside of the screed should be completely insulated and thermostatic regulators set in the floor and the room.

Block heaters – these are rated between 1 kW and 6 kW and incorporate concrete blocks to absorb the off-peak energy (see next page).

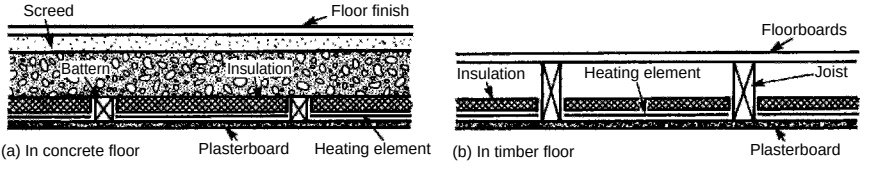


Section through solid ground floor with heating cables



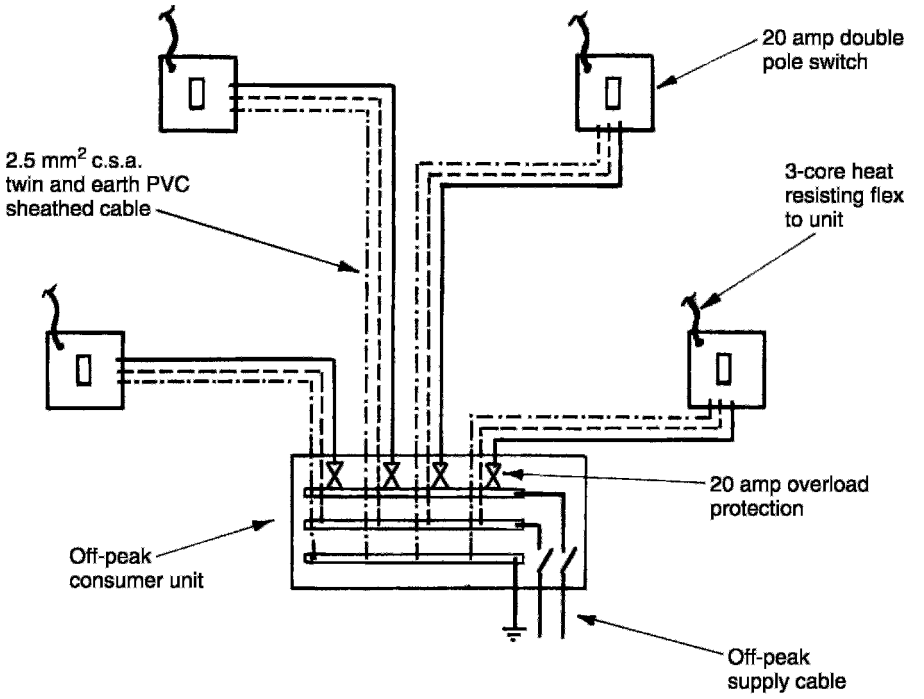
Block storage heater with fan

Electrically heated ceilings use standard tariff electricity supply. The heating element is flexible glasscloth with a conducting silicone elastomer.



Ceiling heating

Night storage heaters – these have developed from very bulky cabinets containing concrete blocks which effectively absorb the overnight electrical energy and dissipate it gradually during the next day. Improvements in storage block material have considerably reduced the size of these units to compare favourably with conventional hot water radiators. They contain a number of controls, including a manually set input thermostat on each heater, an internal thermostat to prevent overheating and a time programmed fan. Manufacturers provide design tables to establish unit size. As a rough guide, a modern house will require about 200 W output per square metre of floor area. Storage heaters are individually wired on radial circuits from the off-peak time controlled consumer unit.

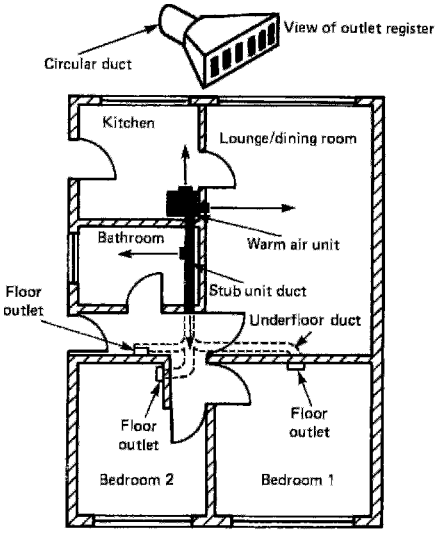


Radial supply to storage heaters

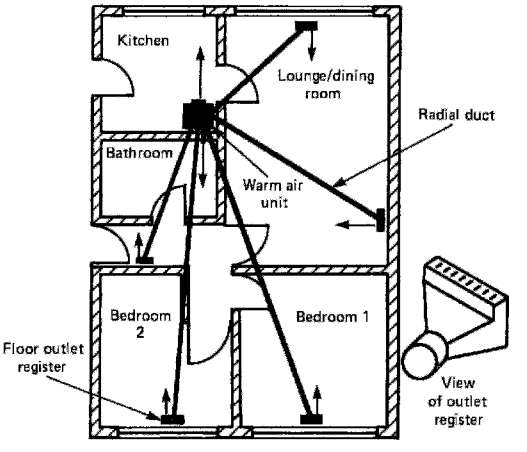
Electrically heated warm air systems are a development of the storage heater concept – see previous two pages. A central unit rated from 6 kW to 12 kW absorbs electrical energy off-peak and during the day delivers this by fan to various rooms through a system of insulated ducting. A room thermostat controls the fan to maintain the air temperature at the desired level. Air volume to individual rooms is controlled through an outlet register or diffuser.

Stub duct system – the unit is located centrally and warm air conveyed to rooms by short ducts with attached outlets.

Radial duct system – warm air from the unit is supplied through several radial ducts designated to specific rooms. Outlet registers are located at the periphery of rooms to create a balanced heat distribution.



Plan of a bungalow showing a 'stub' duct warm air system



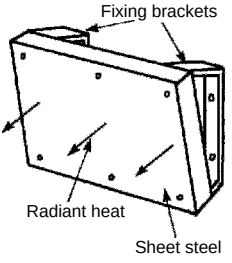
Plan of a bungalow showing a 'radial' duct warm air system

There are numerous types of independent heat emitters for use with 13 amp power sockets or fused spur sockets.

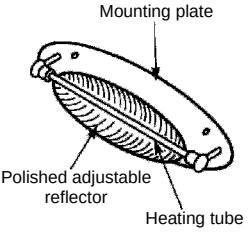
Panel heater – the heat output is mainly radiant from a surface operating temperature of between 204°C and 240°C. For safety reasons it is mounted at high level and may be guarded with a mesh screen.

Infra-red heater – contains an iconel-sheathed element or nickel chrome spiral element in a glass tube, backed by a curved reflector. May be used at high level in a bathroom and controlled with a string pull.

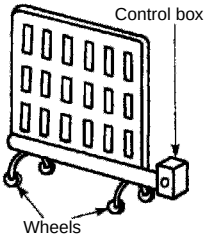
Oil-filled heater – similar in appearance to steel hot water radiators, they use oil as a heat absorbing medium from one or two electrical elements. Heat is emitted by radiant and convected energy. An integral thermostat allows for manual adjustment of output.



Wall-mounted radiant panel heater



Wall-mounted infra-red heater

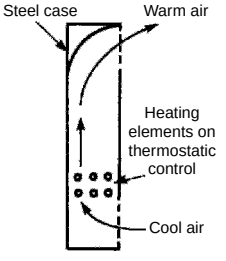


Oil-filled portable heater

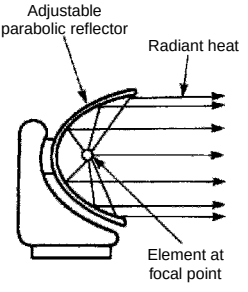
Convector heater – usually has two electrical elements with independent control to vary the output. May be used where a constant level of background warmth is required.

Parabolic reflector fire – has the heating element in the focal point to create efficient radiant heat output.

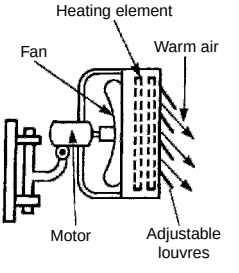
Wall-mounted fan heaters – usually provided with a two-speed fan to deliver air through a bank of electrical elements at varying velocities. Direction is determined by adjustable louvres.



Convector heater



Portable parabolic reflector fire



Wall-mounted fan heater

Controls vary from simple switches and sensors integrated with appliances, to overall system management programmed through time switches and optimisers:

- Manual charge control – set by the user to regulate energy input and output. The effect can be variable and unreliable as it does not take into account inconsistencies such as daily variations in temperature.

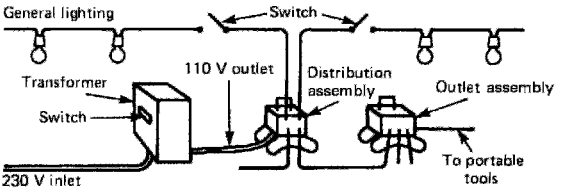
- Automatic charge control – sensors within the heater and room are pre-set to regulate the electrical input charge. When room temperature is high, the sensor in the heater reduces the energy input. Conversely, the energy input is increased when the room temperature is low.

- Heat output control – this is a damper within the heater casing. It can be adjusted manually to regulate heat emission and prevent a room overheating. A variable speed fan can be used to similar effect or to vary the amount of heat emission and its distribution.

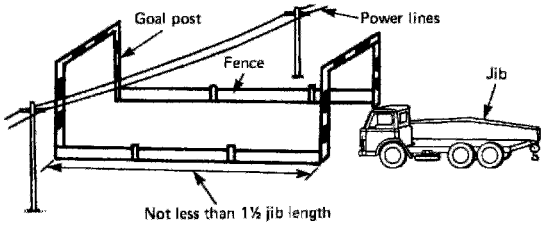
- Time switch/programmer and room thermostat – the simplest type of programmed automatic control applied individually to each heater or as a means of system or group control. Where applied to a system of several emitters, individual heaters should still have some means of manual or preferably automatic regulation. This type of programmed timing is also appropriate for use with direct acting thermostatically switched panel-type heaters.

- `CELECT-type´ controls – this is a type of optimiser control which responds to pre-programmed times and settings, in addition to unknown external influences such as variations in the weather. Zones or rooms have sensors which relate room information to the controller or system manager, which in turn automatically adjusts individual storage heater charge periods and amount of energy input to suit the room criteria. This type of control can also be used for switching of panel heaters.

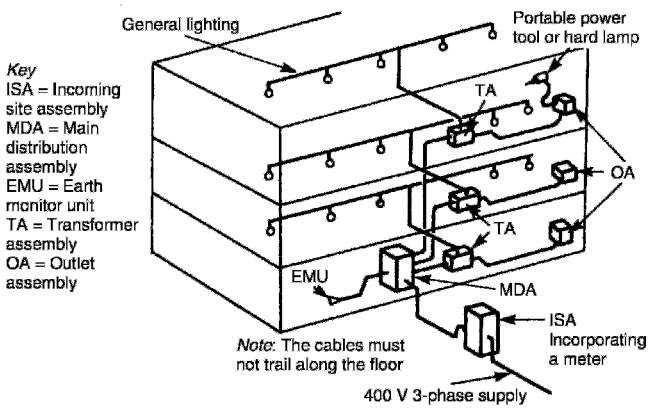
A temporary supply of electricity for construction work may be obtained from portable generators. This may be adequate for small sites but most developments will require a mains supply, possibly up to 400 volts in three phases for operating hoists and cranes. Application must be made in good time to the local electricity authority to ascertain the type of supply and the total load. The incoming metered supply provided by the electricity company will be housed in a temporary structure constructed to the authority's approval. Thereafter, site distribution and installation of reduced voltage transformers is undertaken by the developer's electrical contractor subject to the supply company's inspection and testing.



Reduced voltage distribution



Goal posts (or barrier fences) give protection against contact with overhead power lines



Typical arrangement of distribution units and equipment

Equipment:

Incoming site assembly (ISA) – provided by the local electricity supply company. It contains their switchgear, overload protection, transformers and meters for a 400 volt, three-phase supply at 300, 200 and 100 amps.

Main distribution assembly (MDA) – contains three-phase and single-phase distribution boards, overload protection and lockable switchgear. May be combined with the ISA to become an ISDA.

Transformer assembly (TA) – supplied from the MDA to transform voltage down to 110 V, 50 V and possibly 25 V for use in very damp situations.

Earth monitor unit (EMU) – used where mobile plant requires flexible cables at mains voltage. A very low-voltage current is conducted between plant and EMU and earth conductor, so that if this is interrupted by a fault a monitoring unit disconnects the supply.

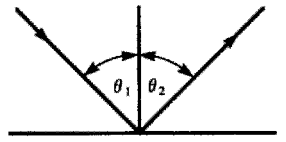
Socket outlet assembly (SOA) – a 110 volt supply source at 32 amps with switchgear and miniature circuit breakers for up to eight 16 amp double pole sockets to portable tools.

Cable colour codes and corresponding operating voltage:

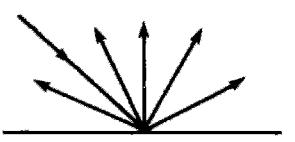
Colour	Voltage
Violet	25
White	50
Yellow	110
Blue	230
Red	400
Black	500/650

Refs: BS 4363: Specification for distribution assemblies for reduced low-voltage electricity supplies for construction and building sites.
BS 7375: Code of practice for distribution of electricity on construction and building sites.
BS EN 60439-4: Low-voltage switchgear and control assemblies. Particular requirements for assemblies for construction sites.

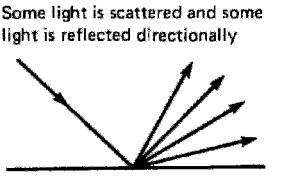
Light is a form of electromagnetic radiation. It is similar in nature and behaviour to radio waves at one end of the frequency spectrum and X-rays at the other. Light is reflected from a polished (specular) surface at the same angle that strikes it. A matt surface reflects in a number of directions and a semi-matt surface responds somewhere between a polished and a matt surface.



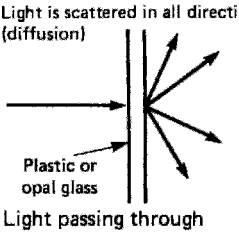
Light reflected from a polished surface



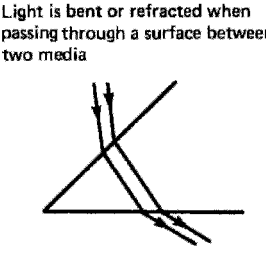
Light reflected from a matt surface

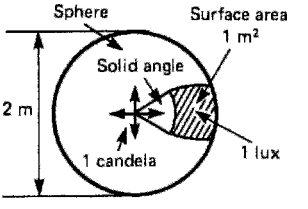


Light scattered and reflected from a semi-matt surface



Light passing through a diffusing screen





Intensity of light and lux

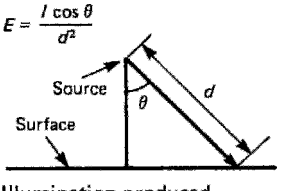
Illumination produced from a light source perpendicular to the surface:

$$E = I \div d^2$$

E = illumination on surface (lux)

I = Illumination intensity from source (cd)

d = distance from light source to surface (m).



Illumination produced from a light source not perpendicular to the surface

Definitions and units of measurement:

- Luminous intensity – candela (cd), a measurement of the magnitude of luminance or light reflected from a surface, i.e. cd/m^2.
- Luminous flux – lumen (lm), a measurement of the visible light energy emitted.
- Illuminance – Lumens per square metre (lm/m^2) or lux (lx), a measure of the light falling on a surface.
- Efficacy – efficiency of lamps in lumens per watt (lm/W). Luminous efficacy = Luminous flux output ÷ Electrical power input.
- Glare index – a numerical comparison ranging from about 10 for shaded light to about 30 for an exposed lamp. Calculated by considering the light source size, location, luminances and effect of its surroundings.

Examples of illumination levels and limiting glare indices for different activities:

Activity/location	Illuminance (lux)	Limiting glare index
Assembly work: (general)	250	25
(fine)	1000	22
Computer room	300	16
House	50 to 300*	n/a
Laboratory	500	16
Lecture/classroom	300	16
Offices: (general)	500	19
(drawing)	750	16
Public house bar	150	22
Shops/supermarkets	500	22
Restaurant	100	22

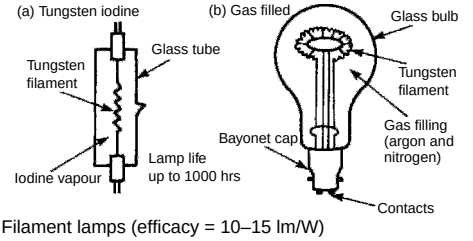
* Varies from 50 in bedrooms to 300 in kitchen and study.

The Building Regulations, Approved Document L2 requires that non-domestic buildings have reasonably efficient lighting systems and make use of daylight where appropriate.

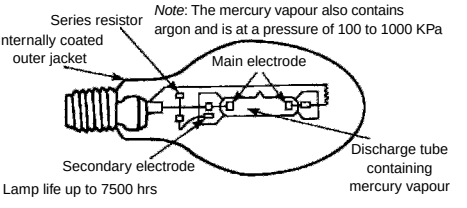
Filament lamps – the tungsten iodine lamp is used for floodlighting. Evaporation from the filament is controlled by the presence of iodine vapour. The gas-filled, general-purpose filament lamp has a fine tungsten wire sealed within a glass bulb. The wire is heated to incandescence (white heat) by the passage of an electric current.

Discharge lamps – these do not have a filament, but produce light by excitation of a gas. When voltage is applied to the two electrodes, ionisation occurs until a critical value is reached when current flows between them. As the temperature rises, the mercury vaporises and electrical discharge between the main electrodes causes light to be emitted.

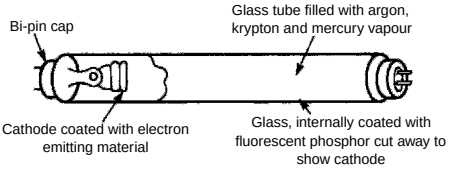
Fluorescent tube – this is a low pressure variation of the mercury discharge lamp. Energised mercury atoms emit ultra-violet radiation and a blue/green light. The tube is coated internally with a fluorescent powder which absorbs the ultra-violet light and re-radiates it as visible light.



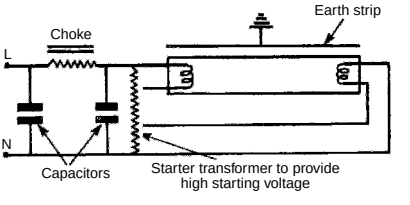
Filament lamps (efficacy = 10–15 lm/W)



Mercury-vapour discharge lamp (efficacy = 50 lm/w)

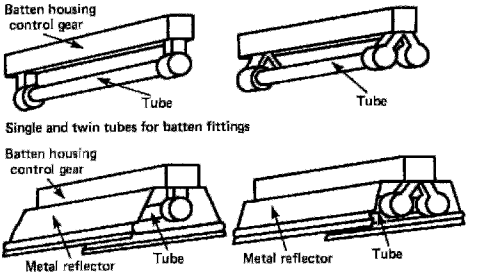


Fluorescent tube (efficacy = 20–60 lm/W)

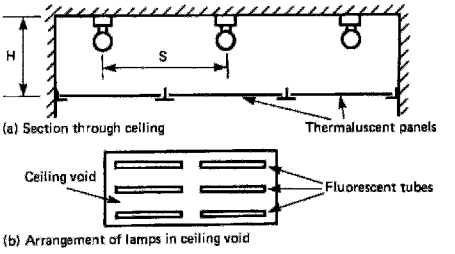


Control gear is needed to start the discharge and to keep the light steady during operation. A transformer provides a quick start.

Fluorescent strip lamps have many applications. The fittings and reflectors shown are appropriate for use in industrial locations, with a variation which creates an illuminated ceiling more suited to shops and offices. A false ceiling of thermaluscent panels provides well-diffused illumination without glare and contributes to the insulation of the ceiling. Other services should not be installed in the void as they will cast shadows on to the ceiling. Tubes are mounted on batten fittings and the inside of the void should be painted white to maximise effect.

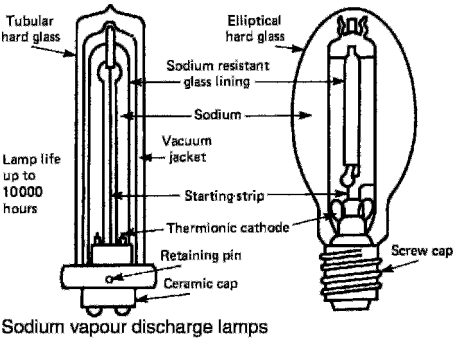


Fittings used for fluorescent lamps



Luminous ceiling

High pressure sodium discharge lamps produce a consistent golden white light in which it is possible to distinguish colours. They are suitable for floodlighting, commercial and industrial lighting and illumination of highways. The low pressure variant produces light that is virtually monochromatic. The colour rendering is poor when compared to the high pressure lamp. Sodium vapour pressure for high and low pressure lamps is 0·5 Pa and 33 kPa, and typical efficacy is 125 and 180 lm/W respectively.

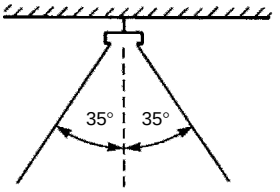


Sodium vapour discharge lamps

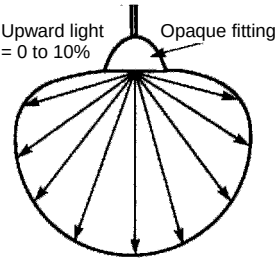
Fittings for lighting may be considered in three categories:

1. General utility – designed to be effective, functional and economic.
2. Special – usually provided with optical arrangements such as lenses or reflectors to give directional lighting.
3. Decorative – designed to be aesthetically pleasing or to provide a feature, rather than to be functional.

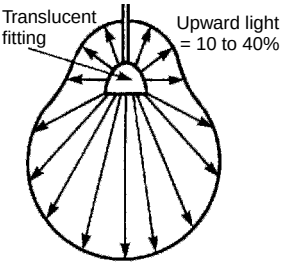
From an optical perspective, the fitting should obscure the lamp from the discomfort of direct vision to reduce the impact of glare.



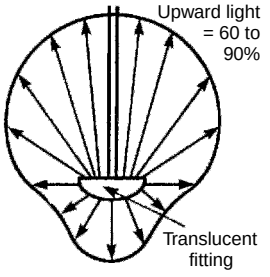
Light emitted within 35° of the vertical will not cause serious glare



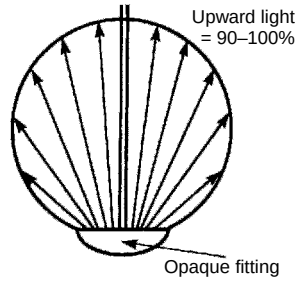
Direct



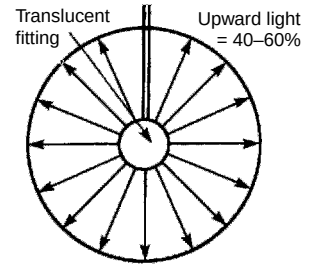
Semi-direct



Semi-indirect

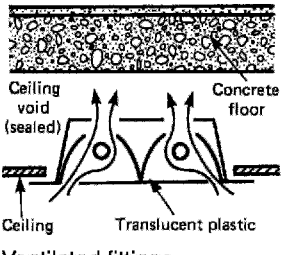


Indirect

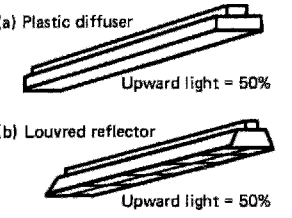


General diffusing

Ventilated fittings allow the heat produced by the lamps to be recirculated through a ceiling void to supplement a warm air ventilation system. The cooling effect on the lamp will also improve its efficiency.



Ventilated fittings

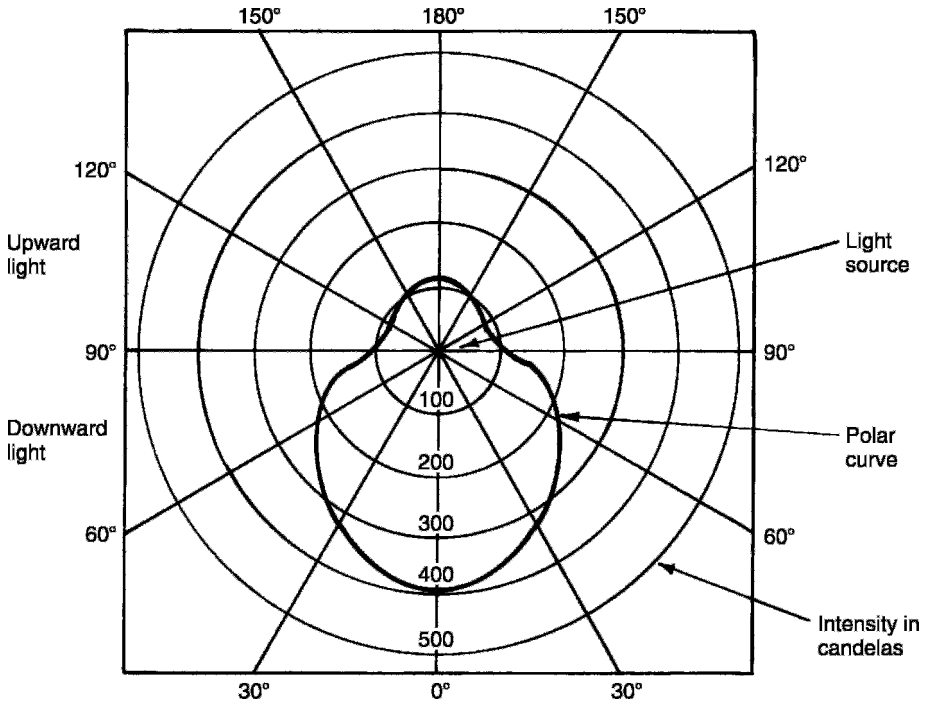


Fittings used for fluorescent lamps

Luminaire – a word to describe the complete lighting unit including the lamp. When selecting a lamp type, it is important to select a luminaire to complement the lamp both functionally and aesthetically. A luminaire has several functions: it defines the lamp position, protects the lamp and may contain the lamp control mechanism. In the interests of safety it must be well insulated, in some circumstances resistant to moisture, have adequate appearance for purpose and be durable.

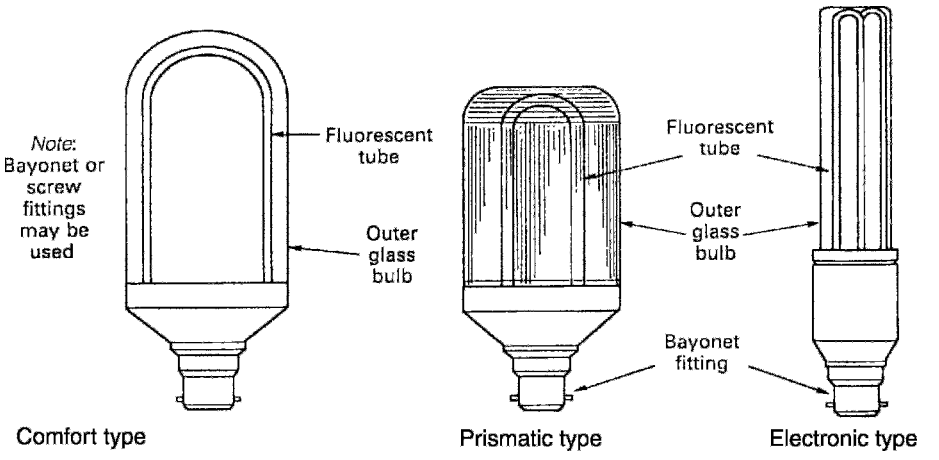
Polar curve – shows the directional qualities of light from a lamp and luminaire by graphical representation, as shown in outline on the previous page. A detailed plot can be produced on polar co-ordinated paper from data obtained by photometer readings at various angles from the lamp. The coordinates are joined to produce a curve.

Typical representation:



Compact fluorescent lamps are a smaller variation and development of the standard fluorescent tube fitting. They are manufactured with conventional bayonet or screw fittings. Unit cost is higher than tungsten filament bulbs but will last over 8000 hours, consuming only about 25% of the energy of a conventional bulb. Tungsten filament bulbs have a life expectancy of about 1000 hours.

The comfort type produces gentle diffused light and is suitable where continuous illumination is required. The prismatic types are more robust and are suitable for application to workshops and commercial premises. Electronic types are the most efficient, consuming only 20% of the energy that would be used in a tungsten filament bulb. Compact fluorescent lamps are not appropriate for use with dimmer switches.



The Buildings Regulations, Approved Document L, lists compact fluorescent lamps as an acceptable means for lighting non-domestic buildings.

Energy Saving Chart

Energy saver	Ordinary light bulb	Energy saving	Over 8000 hours save up to
25 W	100 W	80%	47·70
18 W	75 W	73%	36·25
11 W	60 W	80%	31·16
9 W	40 W	72%	19·72

Domestic energy costed at 7·95p/kWh

Only a small proportion of the energy in a light fitting is converted into light. All the energy dissipated is a measure of heat.

Tungsten filament lamp – heat contribution is the power rating quoted on the bulb.

Fluorescent tube – heat contribution is the power rating plus about 25% attributed to heat energy from the control gear.

High levels of artificial lighting can make a significant contribution to the heating load of a building. This may be useful in winter, but at other times it can cause an overheating problem. A possible solution is combination duct extract/luminaires as shown on pages 196, 197, 199 and 420. Some 40–50% of the lighting heat energy can be directed through a controlled extract or preferably recycled through a heat exchanger. Also, the cooling effect on the light fitting should contribute to its life expectancy. Polyphosphor tubes should not be used in extract luminaries, as the illuminance effect will be reduced.

The following table indicates the approximate heat dissipation, relative to the type of light fitting and level of illuminance:

Illuminance (lux)	Heat dissipation (W/m^2 floor area)				
	Tungsten lamp		Fluorescent tube		
	Open reflector	Diffuser	Open trough	Enclosed diffuser	Louvred ceiling
100	19–25	28–32	4–5	6–8	≅6
200	26–36	33–45	<8	<11	<11
300	37–50	46–69	<11	<16	<17
400	51–65		<15	<22	<23
500	66–88		<25	<27	<30
1000			<38	<54	<60

Proportionate distribution of energy from lamps and tubes:

Energy transfer	Energy dissipated by fitting type (%)		
	Fluorescent	Tungsten	Discharge
Conduction and convection	55	15	40
Radiation	45	85	60

Interior lighting – the energy consumed by lighting in dwellings depends on the overall performance and efficiency of luminaires, lamps and control gear. The Building Regulations require that fixed lighting in a reasonable number of locations where lighting has most use (see table), be fitted with lamps having a luminous efficacy in excess of 40 lumens per circuit-watt. The term circuit-watt is used instead of watt, as this includes the power used by the lamp plus the installation and control gear.

Guidance on number of locations where efficient lighting should be provided:

Rooms created in a dwelling	Minimum number of locations
1–3	1
4–6	2
7–9	3
10–12	4

Hall, stairs and landing are regarded as one room.

An integral (attached to the building) conservatory is considered a room.

Garages, loft and outbuildings are not included.

Exterior lighting – reasonable provisions are required for economic use. This could include any of the following or a combination of:

- efficient lamps
- automatic timed switching control
- photo-electric switching control

Note: Lamps that satisfy the criteria of efficiency include fluorescent tubes and compact fluorescent lamps. Special socket fittings can be made to prevent interchange with unsuitable standard tungsten lamps.

Refs. Building Regulations, Approved Document L1: Conservation of fuel and power in dwellings.
Low energy domestic lighting – ref. GIL 20, BRESCU publications.

Lighting efficiency is expressed as the initial (100 hour) efficacy averaged over the whole building –

Offices, industrial and storage buildings,
not less than 40 luminaire-lumens per circuit-watt.
Other buildings,
not less than 50 lamp-lumens per circuit-watt.
Display lighting,
not less than 15 lamp-lumens per circuit-watt.

A formula and tables for establishing conformity with these criteria are provided in the Building Regulations, Approved Document.

Lighting control objectives:

- to maximise daylight.
- to avoid unnecessary use of artificial lighting when spaces are unoccupied.

Control facilities:

- Local easily accessible manual switches or remote devices including infra-red transmitters, sonic, ultra-sonic and telecommunication controls.
- Plan distance from switch to luminaire, maximum 8 metres or 3 times fitting height above floor (take greater).
- Time switches as appropriate to occupancy.
- Photo-electric light metering switches.
- Automatic infra-red sensor switches which detect the absence or presence of occupants.

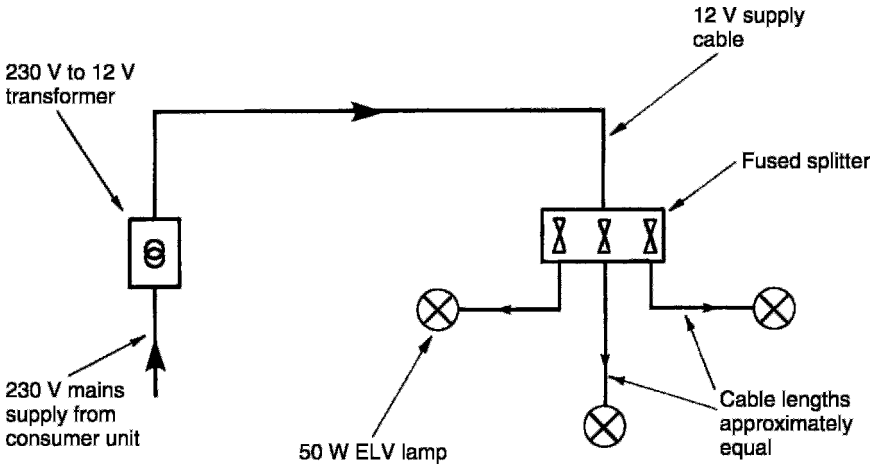
Controls specific to display lighting include dedicated circuits that can be manually switched off when exhibits or merchandise presentations are not required. Timed switching that automatically switches off when premises are closed.

Refs. Building Regulations, Approved Document L2: Conservation of fuel and power in buildings other than dwellings.
BRE Information Paper 2/99, Photo-electric controls of lighting: design, set-up and installation issues.

Extra-low-voltage lighting has application to display lighting for shops and exhibitions. It is also used as feature lighting in domestic premises where set in the ceiling in kitchens and bathrooms. These situations benefit from the low heat emission, good colour rendering and very low running costs of this form of lighting. System potential is only 12 volts a.c., through a transformed 230 volt mains supply. High performance 50 watt tungsten halogen dichroic lamps are compact and fit flush with the mounting surface.

Electricity is supplied from the transformer through a fused splitter to provide a fairly uniform short length of cable to each lamp. Similarity in cable lengths is important to maintain equivalent voltage drop and a short length of cable will minimise voltage drop. Lamps are very sensitive to change in voltage, therefore correct selection of transformer is essential. A voltage drop of 6% (approx. 0·7 volts) will reduce the illuminating effect by about 30%. Cable sizing is also critical with regard to voltage drop. The low voltage creates a high current, i.e. just one 50 watt bulb at 12 volts = 4·17 amps (see page 404 for cable sizing).

Schematic ELV lighting:



Note: A variation is the use of individual low-voltage lamps which contain their own transformer. However, these are relatively expensive items and are attached to special fittings.

The lumen method of lighting design is used to determine a lighting layout that will provide a design maintained illuminance. It is valid if the luminaires are mounted above the working plane in a regular pattern. The method uses the formula: $N = (E \times A) \div (F \times U \times M)$.

N = number of lamps

E = average illuminance on the working plane (lux)

A = area of the working plane (m^2)

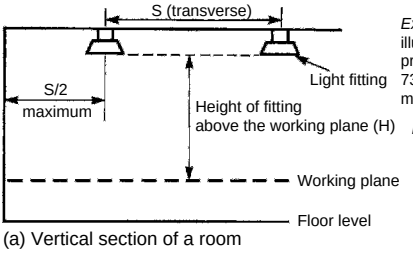
F = flux from one lamp (lumens)

U = utilisation factor

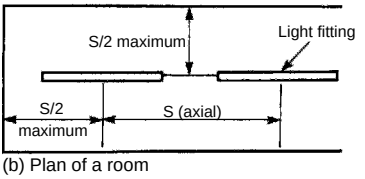
M = maintenance factor.

The utilisation factor (U) is the ratio of the lumens received on the working plane to the total flux output of lamps in the scheme. The maintenance factor (M) is a ratio which takes into account the light lost due to an average expectation of dirtiness of light fittings and surfaces.

Spacing-to-height ratio (SHR) is the centre-to-centre (S) distance between adjacent luminaires to their mounting height (H) above the working plane. Manufacturers' catalogues can be consulted to determine maximum SHRs, e.g. a luminaire with trough reflector is about 1·65 and an enclosed diffuser about 1·4.



(a) Vertical section of a room

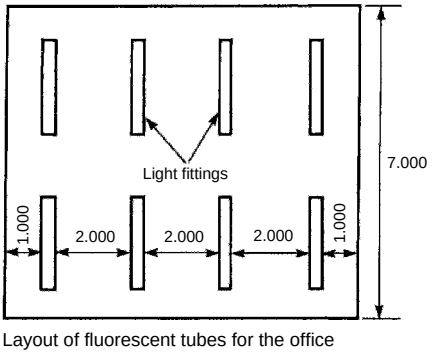


(b) Plan of a room

Method of spacing fluorescent tubes

Example. An office 8 m long by 7 m wide requires an illumination level of 400 lux on the working plane. It is proposed to use 80 W fluorescent fittings having a rated output of 7375 lumens each. Assuming a utilisation factor of 0.5 and a maintenance factor of 0.8 design the lighting scheme.

$$N = \frac{E \times A}{F \times U \times M} \quad \therefore N = \frac{400 \times 8 \times 7}{7375 \times 0.5 \times 0.8} \quad N = 7.59, \text{ use 8 fittings}$$



Layout of fluorescent tubes for the office

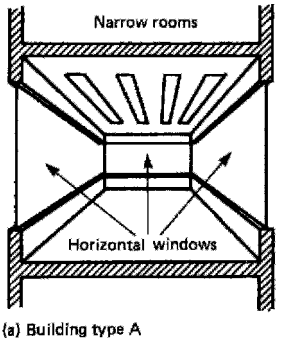
Illumination of building interiors is a very important factor for designers. This will relate to user convenience and visual impact of the building. Overall considerations fall into three categories:

A – daylighting alone, in which the window area occupies about 80% of the facades

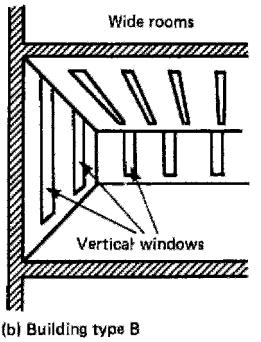
B – permanent supplementary artificial lighting of interiors, in which the window area is about 20% of the facades

C – permanent artificial lighting of interiors in which there are no windows.

Occupants of buildings usually prefer a view to the outside. Therefore the choice of lighting for most buildings is from type A or B. With type B the building may be wider, because artificial lighting is used to supplement daylighting. Although the volume is the same as type A the building perimeter is less, thus saving in wall construction. Type B building also has lower heat gains and energy losses through the glazing, less noise from outside and less maintenance of windows.

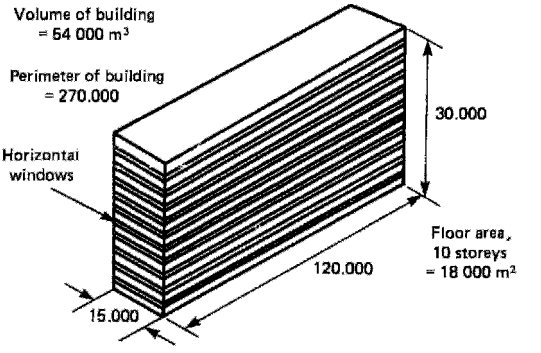


(a) Building type A

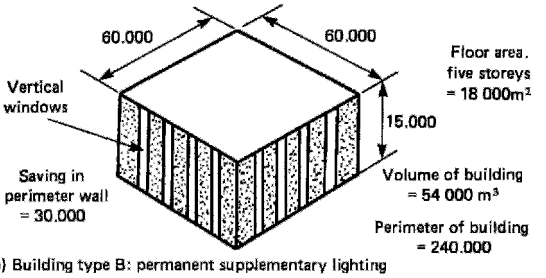


(b) Building type B

View of interior of buildings



(a) Building type A: daylighting



(b) Building type B: permanent supplementary lighting

Elevations of alternative forms of building

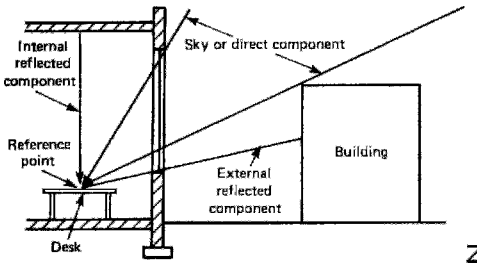
Ref: BS ISO 8995: Lighting of indoor work places.

The daylight received inside a building can be expressed as 'the ratio of the illumination at the working point indoors, to the total light available simultaneously outdoors'. This can also be expressed as a percentage and it is known as the 'daylight factor'.

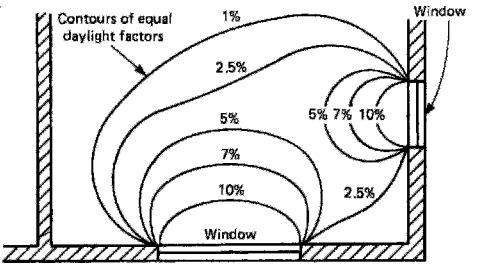
The daylight factor includes light from:

- Sky component – light received directly from the sky; excluding direct sunlight.
- External reflected component – light received from exterior reflecting surfaces.
- Internal reflected component – light received from internal reflecting surfaces.

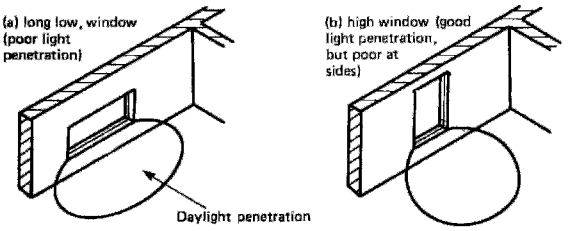
If equal daylight factor contours are drawn for a room, they will indicate how daylighting falls as distance increases from a window.



Components of 'daylight factor'



Typical contours of daylight factor



The effectiveness of window design

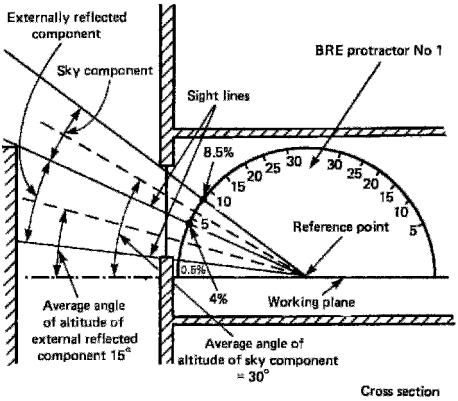
Refs: BRE Digest 309: Estimating daylight in buildings.
BS 8206-2: Lighting for buildings. Code of practice for daylighting.

The effect of daylight in a room can be studied by using scaled models. Providing that textures and colours of a room surface are the same, an approximate result may be obtained.

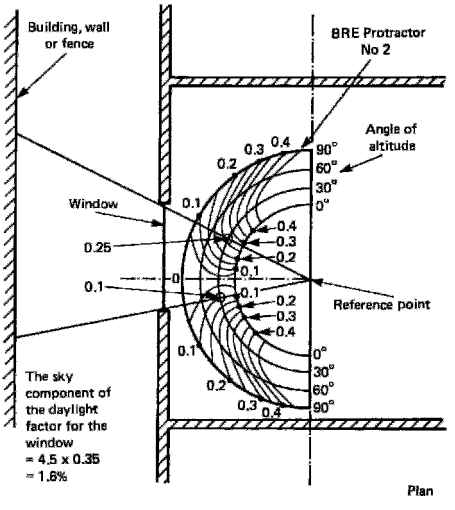
An estimate of the effect of daylight in a room may also be made from daylight factor protractors and associated tables of data. These were developed by the Building Research Establishment for use with scaled drawings to determine the sky component from a sky of uniform luminance.

There are pairs of protractors to suit different window types. Protractor No. 1 is placed on the cross-section as shown. Readings are taken where the sight lines intersect the protractor scale.

In the diagram, the sky component = 8·5 – 4 = 4·5% and an altitude angle of 30°. The sky component of 4·5% must be corrected by using protractor No. 2. This is placed on the plan as shown. Readings from protractor No. 2 are 0·25 and 0·1, giving a total correction factor of 0·35. Therefore 4·5 × 0·35 = 1·6%.



Use of BRE protractor No 1 (vertical windows)



Use of BRE protractor No 2 (vertical windows)

Note: Daylight protractors number 1 to 10. They are available with a guide from the Building Research Establishment, ref. Publication code AP80

The external reflected component of the daylight factor for a uniform sky may be taken as approximately 0·1 x the equivalent sky component. Using the diagrams shown in Daylighting – 2, the value may be found as follows:

- Readings from protractor No. 1 are 4% and 0·5%.
- Equivalent sky component = 4% – 0·5% = 3.5%.
- Average angle of altitude = 15°.
- Readings on protractor No. are 0·27 and 0·09 (for 15°).
- Correction factor = 0·27 + 0·09 = 0·36.
- Equivalent uniform sky component = 3·5% × 0·36 = 1·26%.
- Externally reflected component = 0·1 × 1·26% = 0·126%.

To establish the daylight factor, the internal reflected component is calculated and added to both the sky and externally reflected components – see example.

Example: Find the minimum internally reflected component of the daylight factor for a room measuring 10 m × 8 m × 2·5 m high, having a window in one wall with an area of 20 m^2. The floor has an average reflection factor of 20% and the walls and ceiling average reflection factors of 60% and 70% respectively.

Window area as a percentage of floor area $= \frac{20}{80} \times \frac{100}{1} = 25\%$

Referring to Table 2 (p. 432) the minimum internally reflected component = 1·3%.

Allowing a maintenance factor of 0·9 for dirt on the windows the value will be modified to 1·3 × 0·9 = 1·17%.

For the example given in daylighting 2 and 3 the daylight factor will be the addition of the three components = 1·6 + 0·126 + 1·17 = 2·9%.

Table 1 Reflection factors

Reflection factors (%)		Reflection factors (%)	
White	75–88	Golden yellow	62
Light stone	53	Orange	36
Middle stone	37	Eau-de-nil	48
Light buff	60	Sky blue	47
Middle buff	43	Turquoise	27
Light grey	44	Light brown	30
Dark grey	26	Middle brown	20
Pale cream	73	Salmon pink	42

Table 2 Minimum internally reflected component of the daylight factor (%)

Ratio of window area to floor area	Window area as a percentage of floor area	Floor reflection factor (%)											
		10				20				40			
		Wall reflection factor (per cent)											
		20	40	60	80	20	40	60	80	20	40	60	80
		%	%	%	%	%	%	%	%	%	%	%	%
1:50	2			0·1	0·2		0·1	0·1	0·2		0·1	0·2	0·2
1:20	5	0·1	0·1	0·2	0·4	0·1	0·2	0·3	0·5	0·1	0·2	0·4	0·6
1:14	7	0·1	0·2	0·3	0·5	0·1	0·2	0·4	0·6	0·2	0·3	0·6	0·8
1:10	10	0·1	0·2	0·4	0·7	0·2	0·3	0·6	0·9	0·3	0·5	0·8	1·2
1:6·7	15	0·2	0·4	0·6	1·0	0·2	0·5	0·8	1·3	0·4	0·7	1·1	1·7
1:5	20	0·2	0·5	0·8	1·4	0·3	0·6	1·1	1·7	0·5	0·9	1·5	2·3
1:4	25	0·3	0·6	1·0	1·7	0·4	0·8	1·3	2·0	0·6	1·1	1·8	2·8
1:3·3	30	0·3	0·7	1·2	2·0	0·5	0·9	1·5	2·4	0·8	1·3	2·1	3·3
1:2·9	35	0·4	0·8	1·4	2·3	0·5	1·0	1·8	2·8	0·9	1·5	2·4	3·8
1:2·5	40	0·5	0·9	1·6	2·6	0·6	1·2	2·0	3·1	1·0	1·7	2·7	4·2
1:2·2	45	0·5	1·0	1·8	2·9	0·7	1·3	2·2	3·4	1·2	1·9	3·0	4·6
1:2	50	0·6	1·1	1·9	3·1	0·8	1·4	2·3	3·7	1·3	2·1	3·2	4·9

Note: The ceiling reflection factor is assumed to be 70%.

There are other methods for determining daylight factor. Some are simple rules of thumb and others more detailed formulae. An example of each are shown below.

- Rule of thumb – $D = 0{\cdot}1 \times P$
  where: D = daylight factor
  P = percentage of glazing relative to floor area.

E.g. a room 80 m^2 floor area with 15 m^2 of glazing.

$$D = 0{\cdot}1 \times 15/80 \times 100/1 = 1{\cdot}875\%$$

- Formula –

$$D = \frac{T \times G \times \theta \times M}{A(1 - R^2)}$$

where: D = average daylight factor

T = transmittance of light through glass
(clear single glazing = 0·85, clear double glazing = 0 · 75)

G = glazed area (m^2)

θ = angle of sky component

M = maintenance factor (see page 427)

A = total area of interior surfaces, inc. windows (m^2)

R = reflection factors (see page 432).

E.g. using the data from the example on page 431 and assuming a 50% reflection factor, double glazing and a sky component angle of 35°.

$$D = \frac{0{\cdot}75 \times 20 \times 35 \times 0{\cdot}9}{250\,(1 = [50/100]^2)} = 2{\cdot}52\%$$

All calculations and estimates of daylight factor and glazing area must conform with the basic allowances defined in the Building Regulations, Approved Document L – Conservation of Fuel and Power:

Dwellings: Windows, doors and rooflights – maximum 25% of the total floor area.

Non-domestic buildings:

Residential – windows and personnel doors, maximum 30% of exposed wall area.

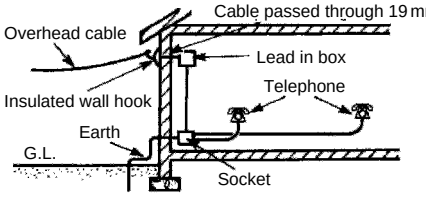
Industrial and storage buildings – windows and personnel doors, maximum 15% of exposed wall area.

Places of assembly, shops and offices – windows and personnel doors, maximum 40% of exposed wall area (excludes display windows).

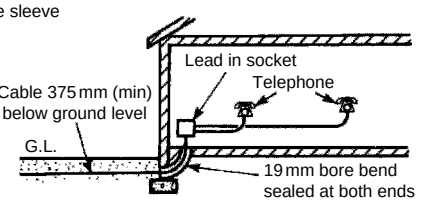
Note: Rooflights in non-domestic, max. 20% of exposed roof area.

Cabling systems that were originally used solely for telephone communications now have many other applications. These include fire alarms, security/intruder alarms, computer networking, teleprinters, facsimile machines, etc. The voltage and current are very low and have no direct connection to the mains electricity in a building. Therefore, telecommunications and mains cabling should be distinctly separated in independent conduits and trunking for reasons of safety and to prevent interference.

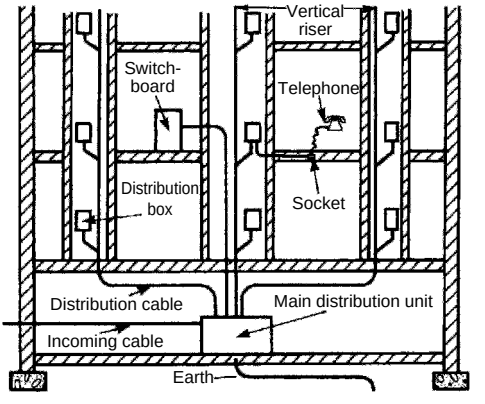
External telecommunications cables may supply a building from overhead or underground, the latter being standard for new building work. The intake is below surface level at a point agreed with the cable supplier. In large buildings the incoming cable supplies a main distribution unit which has connections for the various parts of the building. Cables supply both switchboards and individual telephones from vertical risers. There may be limitations on the number of cables supplied from risers and early consultation with the cable supplier is essential to determine this and any other restrictions.



Overhead telephone cables

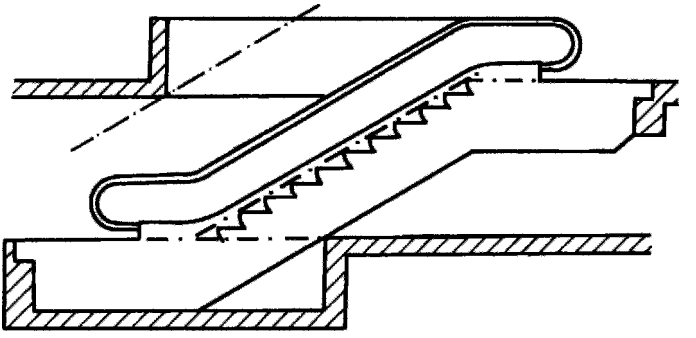


Underground telephone cable



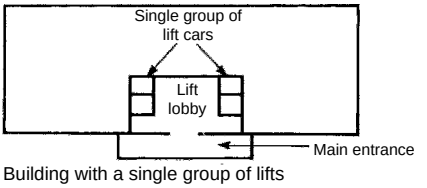
A telephone installation for a large building.
Cables inside the building (not the flexible cord) must be concealed in ducts and the system earthed.

11 MECHANICAL CONVEYORS – LIFTS, ESCALATORS AND TRAVELATORS

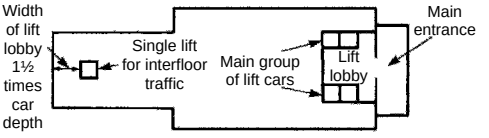


PLANNING LIFT INSTALLATIONS
ELECTRIC LIFTS
ROPING SYSTEMS
CONTROLS
LIFT DOORS
MACHINE ROOM AND EQUIPMENT
SAFETY FEATURES
INSTALLATION DETAILS
DIMENSIONS
PATERNOSTER LIFTS
OIL-HYDRAULIC LIFTS
LIFTING ARRANGEMENTS AND INSTALLATION
PUMPING UNIT
ESTIMATING THE NUMBER OF LIFTS REQUIRED
FIREFIGHTING LIFTS
BUILDERS' AND ELECTRICIANS' WORK
ESCALATORS
TRAVELATORS
STAIR LIFTS

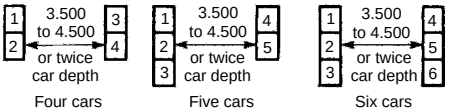
To function efficiently and to provide access for the elderly and disabled, modern offices and public buildings are provided with suitably designed lift installations. Planning (as with all services) should commence early in the design programme. Priority must be given to locating lifts centrally within a building to minimise horizontal travel distance. Consideration must also be given to position, relative to entrances and stairs. Where the building size justifies several passenger lifts, they should be grouped together. In large buildings it is usual to provide a group of lifts near the main entrance and single lifts at the ends of the building. The lift lobby must be wide enough to allow pedestrian traffic to circulate and pass through the lift area without causing congestion. For tall buildings in excess of 15 storeys, high speed express lifts may be used which by-pass the lower floors.



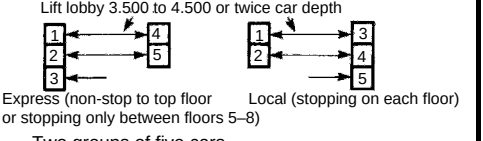
Building with a single group of lifts



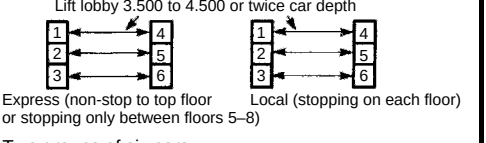
Building with a main group of lifts and also a single lift serving interfloor traffic



Groups of four five or six cars



Two groups of five cars



Two groups of six cars

Requirements:

- Necessary in all buildings over three storeys high.
- Essential in all buildings over a single storey if they are accessed by the elderly or disabled.
- Minimum standard – one lift per four storeys.
- Minimum walking distance to access a lift – 45 m.
- Floor space and lift car capacity can be estimated at 0·2 m^2 per person.

Lift speed:

Type		Car speed (m/s)
Goods (electric or hydraulic)		0·2–1
Electric passenger	<4 floors	0·3–0·8
	4–6 floors	0·8–1·2
	6–9 floors	1·2–1.5
	9–15 floors*	5–7
	paternoster	<0·4
Hydraulic passenger†		0·1–1·0

* Express lift that does not stop at the lower floor levels. The upper speed limit is 7 m/s because of the inability of the human ear to adapt to rapid changing atmospheric conditions.

† Overall theoretical maximum travel distance is 21 m vertically, therefore limited to four or five storeys.

Electric motor – low speed lifts operate quite comfortably with an a.c. motor to drive the traction sheave through a worm gear (see page 444). For faster speed applications a d.c. motor is preferable. This is supplied via a mains generator for each lift motor. D.c. motors have historically provided better variable voltage controls, more rapid and smoother acceleration, quieter operation, better floor levelling and greater durability in resisting variable demands. Recent developments with a.c. motors have made them more acceptable and these are now becoming more widely used.

Refs: BS 5655: Lifts and service lifts.
BS EN 81: Safety rules for the construction and installation of lifts.
BS 5656: Safety rules for the construction and installation of escalators and passenger conveyors. Specification and pro formas for test and examination of new installations.

High tensile steel ropes are used to suspend lift cars. They have a design factor of safety of 10 and are usually at least four in number. Ropes travel over grooved driving or traction sheaves and pulleys. A counterweight balances the load on the electric motor and traction gear.

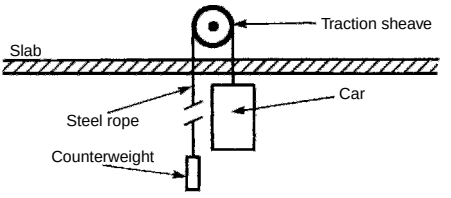
Methods for roping vary:

Single wrap 1:1 – the most economical and efficient of roping systems but is limited in use to small capacity cars.

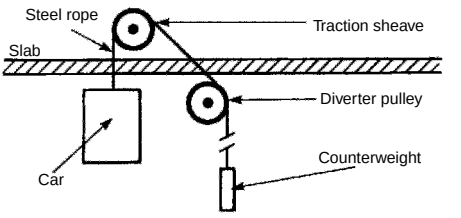
Single wrap 1:1 with diverter pulley – required for larger capacity cars. It diverts the counterweight away from the car. To prevent rope slip, the sheave and pulley may be double wrapped.

Single wrap 2:1 – an alternative for use with larger cars. This system doubles the load carrying capacity of the machinery but requires more rope and also reduces the car speed by 50%.

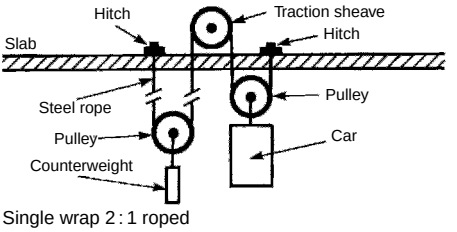
Double wrap – used to improve traction between the counterweight, driving sheave and steel ropes.



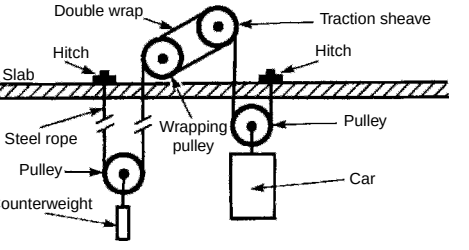
Single wrap 1 : 1 roped



Single wrap 1 : 1 roped with diverter pulley



Single wrap 2 : 1 roped

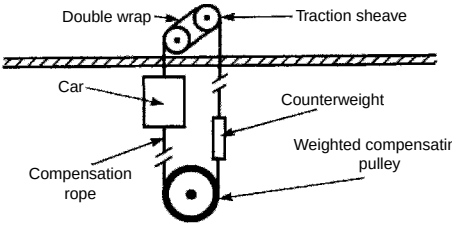


Double wrap 2 : 1 roped (for high speed and medium to heavy duty loads)

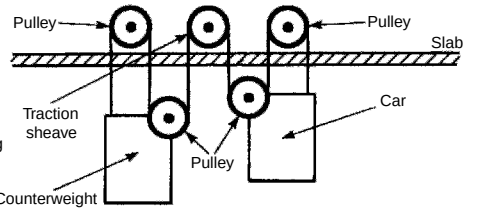
Single wrap 3:1 – used for heavy goods lifts where it is necessary to reduce the force acting upon the machinery bearings and counterweight. The load carrying capacity is increased by up to three times that of uniform ratio, but the capital costs are higher with increased pulleys and greater length of rope. By comparison, the car speed is also reduced to one-third.

Drum drive – a system with one set of ropes wound clockwise around the drum and another set anti-clockwise. It is equally balanced, as one set unwinds the other winds. The disadvantage of the drum drive is that as height increases, the drum becomes less controllable, limiting its application to rises of about 30 m.

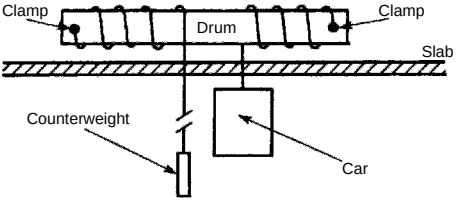
Compensating rope and pulley – used in tall buildings where the weight of the ropes in suspension will cause an imbalance on the driving gear and also a possible bouncing effect on the car. The compensating ropes attach to the underside of car and counterweight to pass around a large compensating pulley at low level.



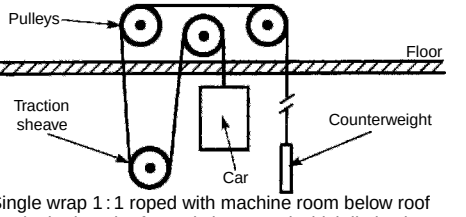
Double wrap 1 : 1 roped with compensating rope



Single wrap 3 : 1 roping

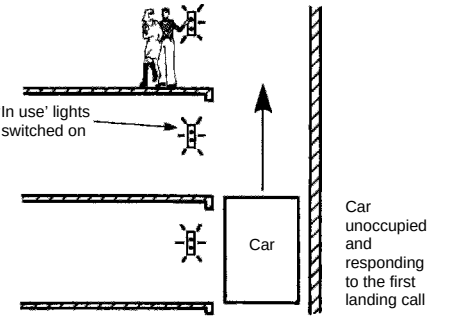


Drum drive

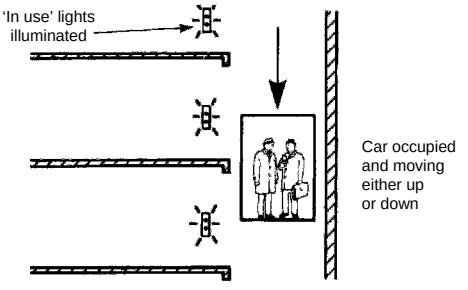


Single wrap 1 : 1 roped with machine room below roof level. The length of rope is increased which limits the travel and speed of car

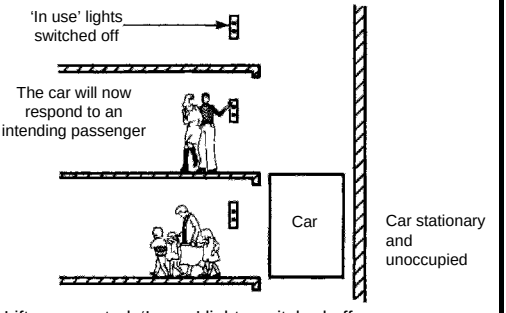
The single automatic push button system is the simplest and least sophisticated of controls. The lift car can be called and used by only one person or group of people at a time. When the lift car is called to a floor, the signal lights engraved `in use´ are illuminated on every floor. The car will not respond to any subsequent landing calls, nor will these calls be recorded and stored. The car is under complete control of the occupants until they reach the required floor and have departed the lift. The `in use´ indicator is now switched off and the car is available to respond to the next landing call. Although the control system is simple and inexpensive by comparison with other systems, it has its limitations for user convenience. It is most suited to light traffic conditions in low rise buildings such as nursing homes, small hospitals and flats.



Lift car called to a floor. 'In use' lights switched on



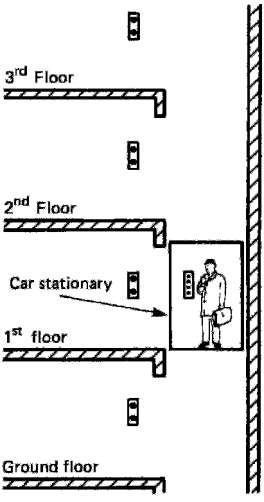
Lift car in control of occupant and cannot be called by other passengers



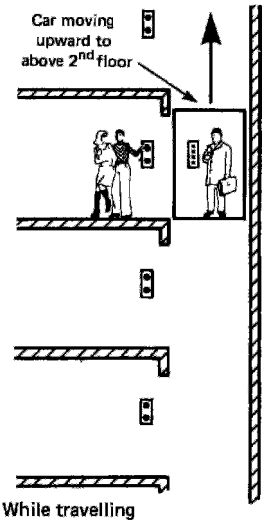
Lift car vacated. 'In use' lights switched off.
Lift can now be called by other passengers

Ref. BS 5655-7: Lifts and service lifts. Specification for manual control devices, indicators and additional fittings.

Down collective – stores calls made by passengers in the car and those made from the landings. As the car descends, landing calls are answered in floor sequence to optimise car movement. If the car is moving upwards, the lift responds to calls made inside the car in floor sequence. After satisfying the highest registered call, the car automatically descends to answer all the landing calls in floor sequence. Ony one call button is provided at landings. This system is most suited to flats and small hotels, where the traffic is mainly between the entrance lobby and specific floors.

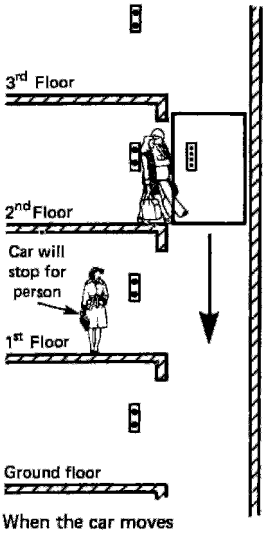


Passenger enters the car and press buttons to travel upwards

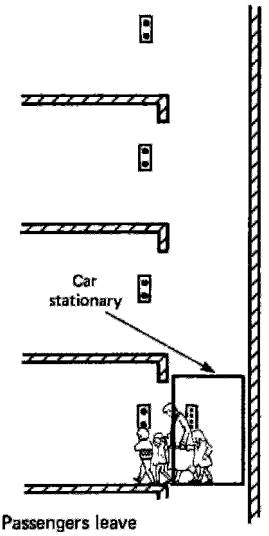


While travelling upwards all the landing calls are by-passed

Full or directional collective – a variation in which car and landing calls are immediately stored in any number. Upward and downward intermediate landing calls are registered from one of two directional buttons. The uppermost and lowest floors only require one button. The lift responds to calls in floor order independent of call sequence, first in one direction and then the other. It has greater flexibility than the down collective system and is appropriate for offices and departmental stores where there is more movement between intermediate floors.



When the car moves down all landing calls are collected floor by floor

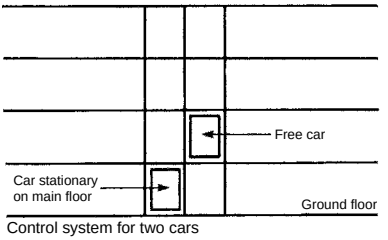


Passengers leave the car

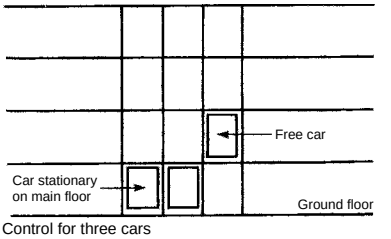
Controls for Two or More Cars

Two cars may be co-ordinated by a central processor to optimise efficiency of the lifts. Each car operates individually on a full or down collective control system. When the cars are at rest, one is stationed at the main entrance lobby and the other, which has call priority, at a mid-point within the building or at another convenient floor level. The priority car will answer landing calls from any floor except the entrance lobby. If the priority car is unable to answer all call demands within a specific time, the other car if available will respond. A similar system may also apply to three cars, with two stationary at the entrance lobby and one available at mid-point or the top floor.

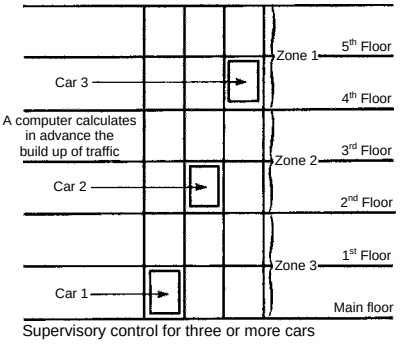
With the supervisory control system, each car operates on full collective control and will respond to calls within a dedicated zone. A micro-processor determines traffic demand and locates cars accordingly to each operating zone.



Control system for two cars

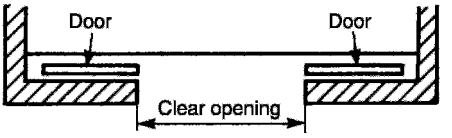


Control for three cars

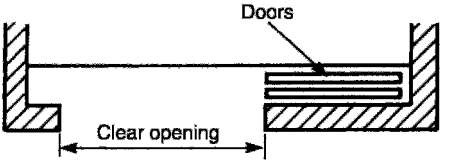


Supervisory control for three or more cars

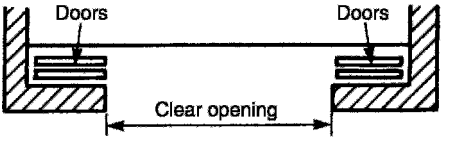
Door operation is by an electric motor through a speed reduction unit, clutch drive and connecting mechanism. The type of entrance and doors form a vital part of the lift installation. The average lift car will spend more time at a floor during passenger transfer time than it will during travel. For general passenger service, either side opening, two-speed or even triple-speed side opening doors are preferred. The most efficient in terms of passenger handling is the two-speed centre opening. The clear opening may be greater and usable clear space becomes more rapidly available to the passengers. Vertical centre-bi-parting doors are suitable for very wide openings, typical of industrial applications.



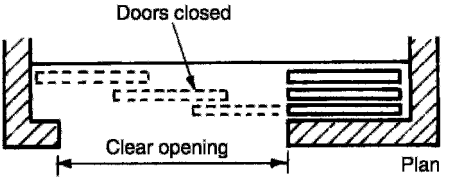
(a) Centre opening



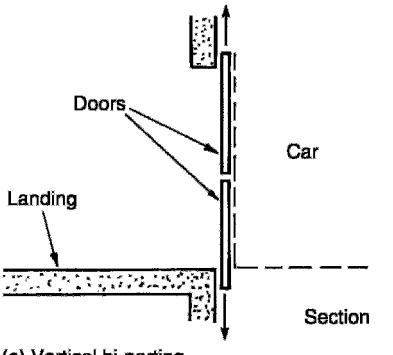
(b) Two-speed side opening



(c) Two-speed centre opening



(d) Triple-speed side opening



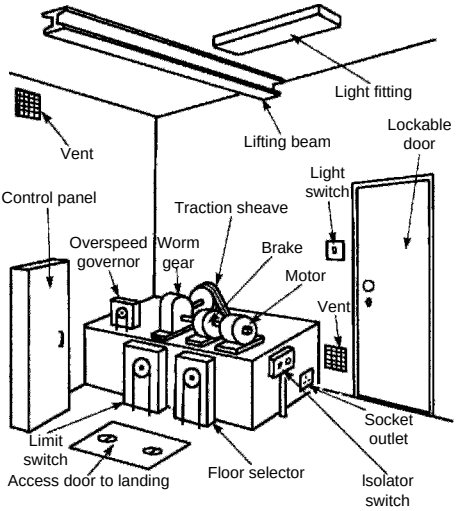
(e) Vertical bi-parting

Lift doors

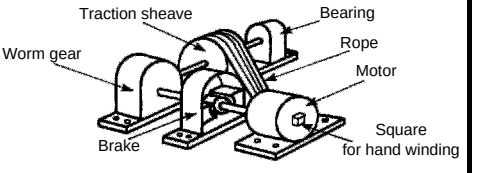
Wherever possible the machine room should be sited above the lift shaft. This location minimises the length of ropes and optimises efficiency. The room should be ventilated, but the vent opening must not be over the equipment. Machinery must be well secured to a concrete base. To reduce sound transmission and vibration, compressed cork, dense rubber or a composite layer is used as an intermediate mounting.

A steel lifting beam is built into the structure above the machinery for positioning or removing equipment for maintenance and repair. Sufficient floor space is necessary for the inspection and repair of equipment – see BS 5655: Lifts and service lifts, for guidance on machine room dimensions relative to capacity.

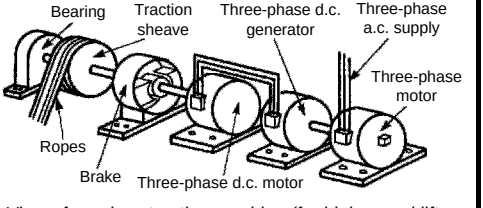
To prevent condensation the room must be well insulated and heated to provide a design air temperature between 10°C and 40°C. Walls, ceiling and floor should be smooth finished and painted to reduce dust formation. A regular pattern of room cleaning and machinery maintenance should be scheduled.



View of machine room



View of geared traction machine (for car speeds up to 0.8 m/s)

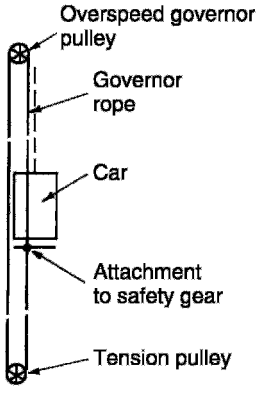


View of gearless traction machine (for high speed lifts, 1.75 m/s and over)

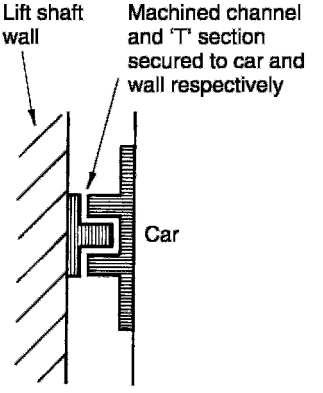
Buffers – located at the base of the shaft. They are usually oil loaded for lift speeds >1·5 m/s and otherwise spring loaded. Some variations use compressible plastics.

Overspeed governor – a steel rope passes round a tension pulley in the pit and a governor pulley in the machine room. It also attaches to the lift car's emergency braking system. Overspeeding locks the governor as it responds to spring loaded fly-weight inertia from the centrifugal force in its accelerating pulley. This also switches off power to the lift. The tightening governor rope actuates the safety braking gear.

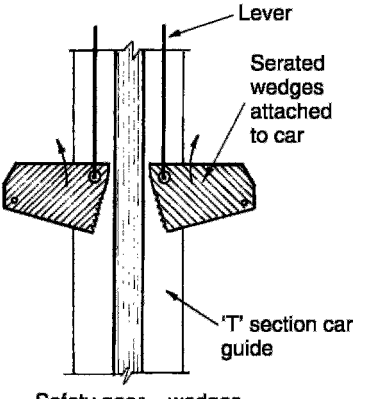
Safety gear – hardened steel wedges are arranged in pairs each side of the lift car to slow down and stop the car by frictional contact with the car guide rail. Slow- and medium-speed lifts have pairs of hardened steel cams which instantaneously contact a steel channel secured to the lift wall.



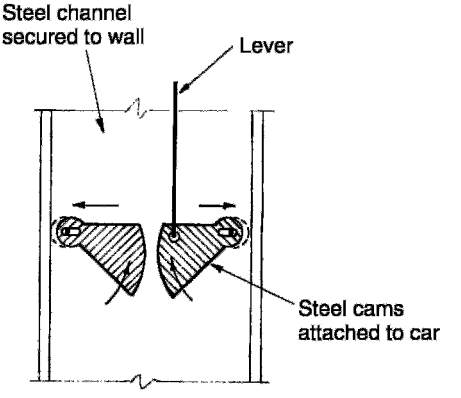
Overspeed governor



Car guide mechanism

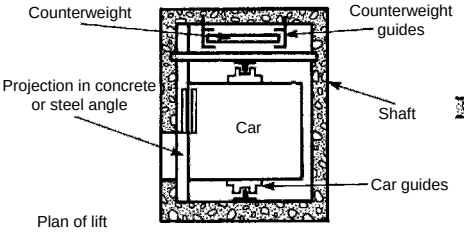


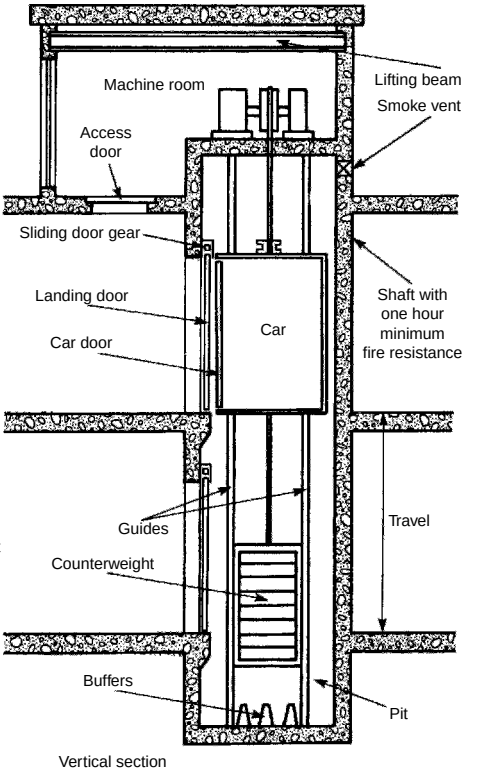
Safety gear – wedges



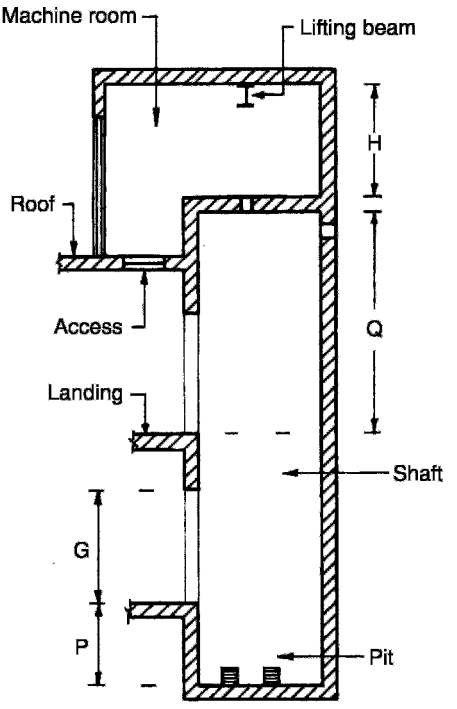
Safety gear – cams

To satisfy the need for economies in lift manufacturing processes, BS 5655 provides a limited range of dimensions. Therefore, architects will have to establish passenger transport requirements as a preliminary design priority. The size of lift shaft will depend upon the car capacity and the space required for the counterweight, guides and landing door. The shaft extends below the lowest level served to provide a pit. This permits a margin for car overtravel and a location for car and counterweight buffers. The pit must be watertight and have drainage facilities. Shaft and pit must be plumb and the internal surfaces finished smooth and painted to minimise dust collection. A smoke vent with an unobstructed area of 0·1 m^2 is located at the top of the shaft. The shaft is of fire resistant construction as defined for `protected shafts' in the Building Regulations. This will be at least 30 minutes and is determined by building function and size. No pipes, ventilating ducts or cables (other than those specifically for the lift) must be fitted within the shaft. A clearance is required at the top of the lift for car overtravel. Counterweight location is at the back or side of the car.



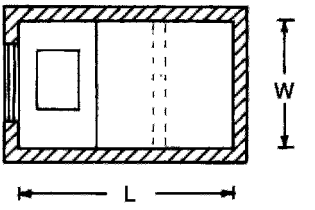


Refs: BS 5655: Lifts and service lifts.
BS EN 81: Safety rules for the construction and installation of lifts.
Building Regulations, Approved Document B3: Internal fire spread (structure).

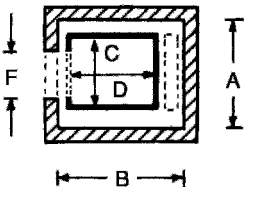


Vertical section

General-purpose electric traction lift



Plan section – machine room



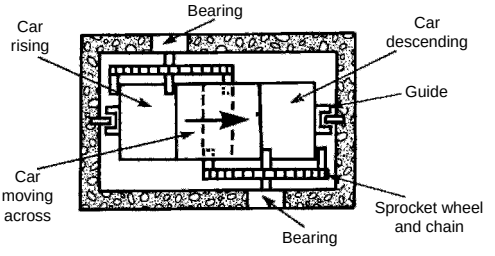
Plan section – shaft and car

All dimensions in metres:

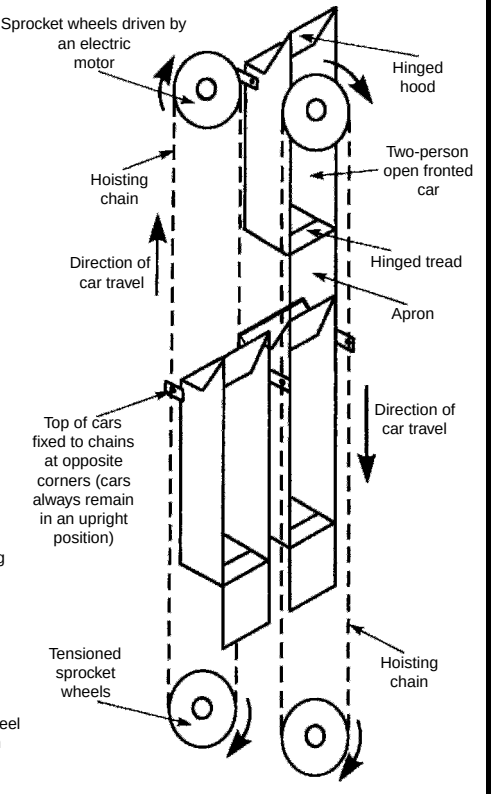
Shaft size		Car size			Door size		Pit	Machine room			
A	B	C	D	E	F	G	P	Q	H	L	W
1·8	2·1	1·1	1·4	2·2	0·8	2·0	1·7	4/4·2	2·6	3·7	2·5
1·9	2·3	1·35	1·4	2·2	0·8	2·0	1·7	4/4·2	2·6	3·7	2·5
2·4	2·3	1·6	1·4	2·3	1·1	2·1	1·8	4·2	2·7	4·9	3·2
2·6	2·3	1·95	1·4	2·3	1·1	2·1	1·9	4·4	2·7	4·9	3·2
2·6	2·6	1·95	1·75	2·3	1·1	2·1	1·9	4·4	2·8	5·5	3·2

Note: Dimension E refers to the car door height.

A paternoster consists of a series of open fronted two-person cars suspended from hoisting chains. Chains run over sprocket wheels at the top and bottom of the lift shaft. The lift is continuously moving and provides for both upward and downward transportation of people in one shaft. Passengers enter or leave the car while it is moving, therefore waiting time is minimal. Passengers will have to be fairly agile, which limits this type of installation to factories, offices, universities, etc. It is not suitable in buildings that accommodate the infirm or elderly! When a car reaches its limit of travel in one direction, it moves across to the adjacent set of hoisting chains to engage with car guides and travel in the other direction. In the interests of safety, car speed must not exceed 0·4 m/s.



Plan of lift at top changeover



View of installation

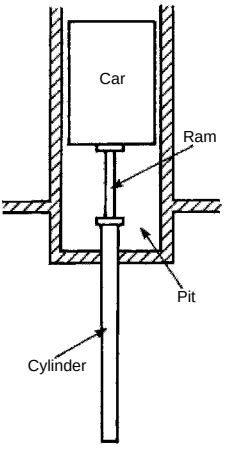
Paternosters convey about 600 persons per hour. This type of lift has the advantage of allowing passengers to begin their journeys undelayed, regardless of travel direction. Simplicity of control gear adds to the advantages, resulting in fewer breakdowns by eliminating normal processes of stopping, starting, accelerating and decelerating. They are most suited to medium-rise buildings.

Direct acting – the simplest and most effective method, but it requires a borehole below the pit to accommodate the hydraulic ram. The ram may be one piece or telescopic. In the absence of a counterweight, the shaft width is minimised. This will save considerably on construction costs and leave more space for general use.

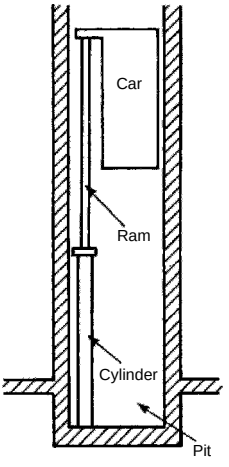
Side acting – the ram is connected to the side of the car. For large capacity cars and heavy goods lifts, two rams may be required, one each side of the car. A borehole is not necessary, but due to the cantilever design and eccentric loading of a single ram arrangement, there are limitations on car size and load capacity.

Direct side acting – the car is cantilevered and suspended by a steel rope. As with side acting, limitations of cantilever designs restrict car size and payload. Car speed may be increased.

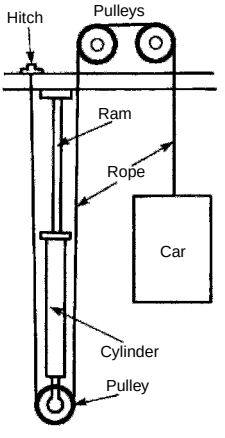
Indirect side acting – the car is centrally suspended by a steep rope and the hydraulic system is inverted.



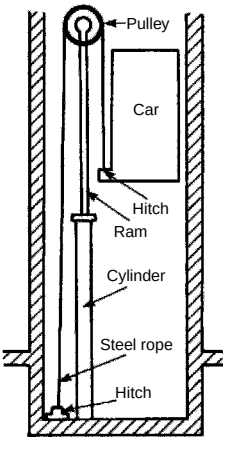
Direct acting



Side acting



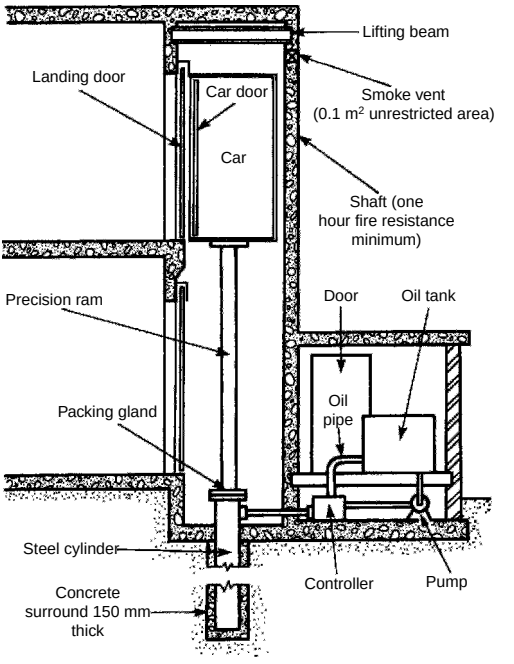
Direct side acting



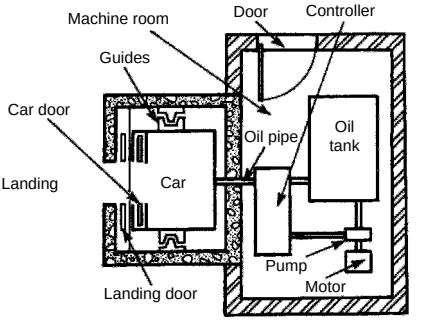
Indirect side acting

Details of Oil-hydraulic Lift Installation

Originally, hydraulic lifts used mains water supply as the operating medium. The main was pressurised from a central pumping station to service lift installations in several buildings. The oil-hydraulic system has oil pressure fed by a pump into a cylinder to raise the ram and lift car. Each lift has its own pumping unit and controller. These units are usually sited at or near to the lowest level served, no more than 10 m from the shaft. The lift is ideal in lower rise buildings where moderate speed and smooth acceleration is preferred. Car speed ranges from 0·1 to 1 m/s and the maximum travel is limited to about 21 m. The lift is particularly suitable for goods lifts and for hospitals and old people's homes. Most hydraulic lifts carry the load directly to the ground, therefore as the shaft does not bear the loads, construction is less expensive than for a comparable electric lift installation.



Vertical section



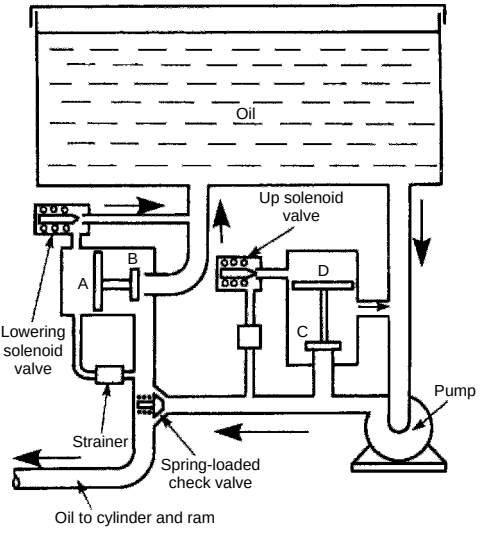
Plan

BS 5655-10·2 provides specific guidance for the testing and examination of hydraulic lifts.
See also BS EN 81-2 for safety rules applied to constructing and installing hydraulic lifts.

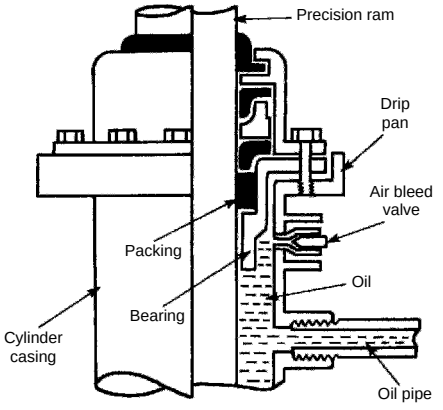
Upward movement – the oil pressure must be gradually increased. The up solenoid valve is energised by an electric current and opens to allow oil to enter above piston D. As the area of piston D is greater than valve C, the oil pressure closes the valve and allows high pressure oil to flow to the cylinder and lift the ram and the car.

Downward movement – the oil pressure must be gradually decreased. The lowering solenoid valve is energised by an electric current and opens allowing oil to flow back to the tank through the by-pass. As the area of piston A is greater than valve B, the reduced oil pressure behind the piston allows valve B to open. Oil flows into the tank and the car moves downwards.

A special packing gland with several seals is required between the cylinder and ram.



Oil tank, pump and controls



Detail of packing gland

Lift performance

Lift performance depends on:

- acceleration;
- retardation;
- car speed;
- speed of door operation; and
- stability of speed and performance with variations of car load.

The assessment of population density may be found by allowing between one person per 9·5 m^2 of floor area to 11·25 m^2 of floor area. For unified starting and finishing times 17% of the population per five minutes may be used. For staggered starting and finishing times 12% of the population may be used.

The number of lifts will have an effect on the quality of service. Four 18-person lifts provide the same capacity as three 24-person lifts but the waiting time will be about twice as long with the three-car group.

The quality of service may be found from the interval of the group. 25–35 seconds interval is excellent, 35–45 seconds is acceptable for offices, 60 seconds for hotels and 90 seconds for flats.

Further criteria for the comfort and convenience of lift users:

- Directional indication of location of the lift lobby for people unfamiliar with the building.
- Call buttons at landings and in the car positioned for ease of use with unambiguous definition for up and down directions.
- Call buttons to be at a level appropriate for use by people with disabilities and small children.
- Call display/car location display at landings to be favourably positioned for a group of people to watch the position of all cars and for them to move efficiently to the first car arriving.
- Call lights and indicators with an audible facility to show which car is first available and in which direction it is travelling.
- Lobby space of sufficient area to avoid congestion by lift users and general pedestrian traffic in the vicinity.

Example: An office block with 20 storeys above ground floor having unified starting and stopping times is to have a floor area above the ground floor of 8000 m^2 and floor pitch of 3 m. A group of four lifts, each car having a capacity of 20 persons and a car speed of 2·5 m/s are specified. The clear door width is to be 1·1 m and the doors are to open at a speed of 0·4 m/s. Estimate the interval and quality of service that is to be provided.

---

1 Peak demand for a 5-minute period $= \dfrac{8000\ m^2 \times 17\%}{11\ m^2/\text{person} \times 100}$

$= 124$ persons

---

2 Car travel $= 20 \times 3$ m $= 60$ m

---

3 Probable number of stops $= S - S\left(\dfrac{S-1}{S}\right)^n$

(where S = maximum number of stops)

$\therefore$ Probable number of stops $= 20 - 20\left(\dfrac{20-1}{20}\right)^{16}$

$= 11$

(where n = number of passengers usually approximately 80% of capacity)

---

4 Upward journey time $= S_1\left(\dfrac{L}{S_1 V} + 2V\right)$

where S_1 = probable number of stops L = travel V = speed

$\therefore$ Upward journey time $= 11\left(\dfrac{60}{11 \times 2{\cdot}5} + 2 \times 2{\cdot}5\right)$

$= 79$ seconds

---

5 Downward journey time $= \left(\dfrac{L}{V} + 2V\right)$

$= \dfrac{60}{2{\cdot}5} + 2 \times 2{\cdot}5$

$= 29$ seconds

---

6 Door operating time $= 2\ (S_1 + 1)\ \dfrac{W}{Vd}$

where W = width of door opening; Vd = opening speed

$\therefore$ Door operating time $= 2\ (11 + 1)\ \dfrac{1{\cdot}1}{0{\cdot}4} = 66$ seconds

---

7 The average time taken for each person to get into and out of a lift car may be taken as 2 seconds

$\therefore$ Transfer time $= 2n = 2 \times 16 = 32$ seconds

---

8 Round trip time $= 79 + 29 + 66 + 32 = 206$ seconds

---

9 Capacity of group $= \dfrac{5\ \text{mins} \times 60 \times 4 \times 20 \times 0{\cdot}8}{206}$

$= 93$ persons per 5 minutes

---

10 Interval for the group $= \dfrac{206}{4} = 51{\cdot}5$ seconds

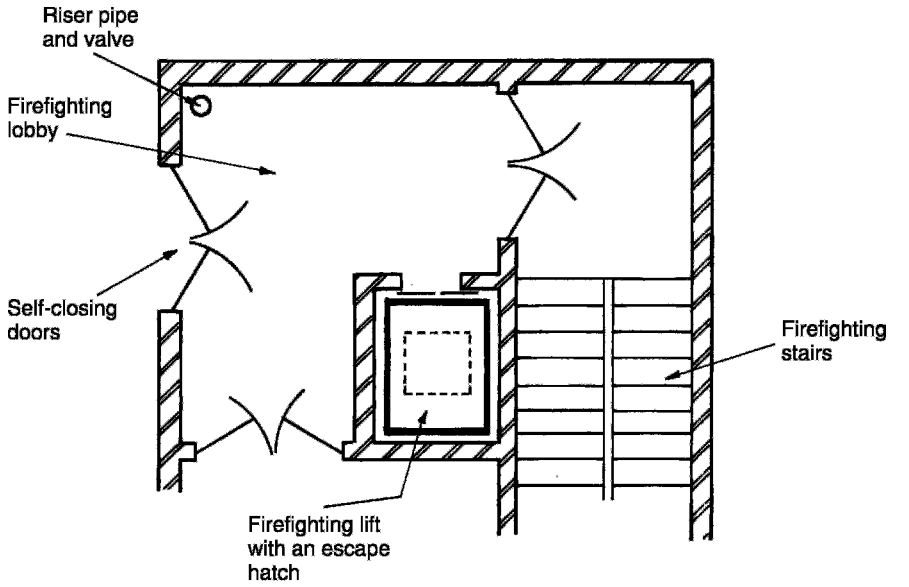
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The capacity of the group of lifts and the interval for the group are satisfactory. (Note: Cars less than 12 capacity are not satisfactory)

During the early part of the twentieth century, it became apparent that the growing number of high rise buildings would require special provisions for fire control. The firefighting lift was conceived as a means of rapidly accessing the upper floors. Early innovations prioritised the passenger lift by means of a `break-glass' key switch which brought the lift to the ground floor immediately. This is now unlikely to be acceptable to building insurers and the fire authorities. It is also contrary to current building standards which specify a separate lift installation specifically for firefighting purposes.

Special provisions for firefighting lifts:

- Minimum duty load of 630 kg.
- Minimum internal dimensions of 1·1 m wide × 1·4 m deep × 2·0 m high.
- Provision of an emergency escape hatch in the car roof.
- Top floor access time – maximum 60 seconds.
- Manufactured from non-combustible material.
- A two-way intercommunications system installed.
- Door dimensions at least 0·8 m wide × 2·0 m high of fire resisting construction.
- Two power supplies – mains and emergency generator.



Firefighting lift in purpose-made shaft

Building Regulations – structures with floors at a height greater than 18 m above fire service vehicle access (usually ground level), or with a basement greater than 10 m below fire service vehicle access, should have accessibility from a purpose-made firefighting lift. All intermediate floors should be served by the lift. Firefighting lifts for other situations are optional as defined in Approved Document B5, Section 18, but will probably be required by the building insurer.

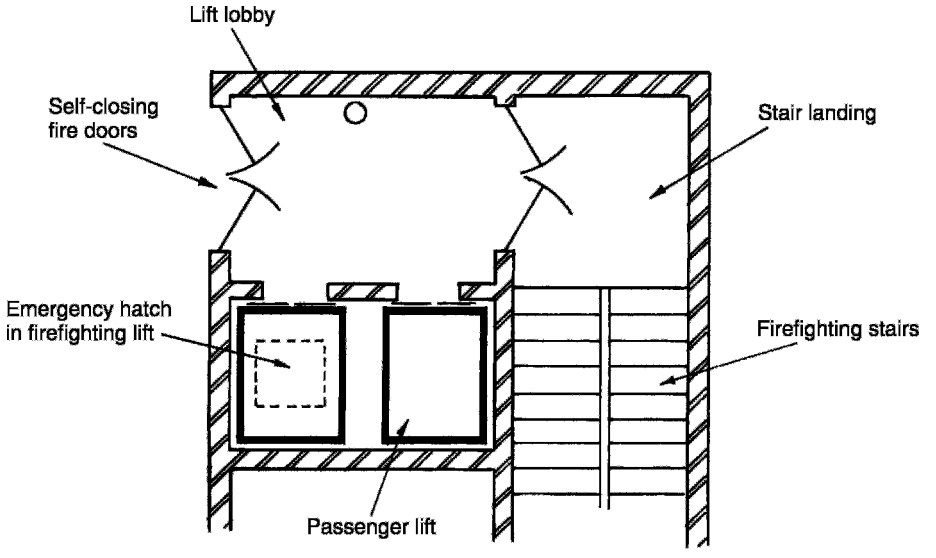
Minimum number of firefighting shafts containing lifts:

Buildings without sprinklers – 1 per 900 m^2 floor area (or part of) of the largest floor.

Buildings with sprinklers < 900 m^2 floor area = 1
900 to 2000 m^2 floor area = 2
> 2000 m^2 floor area = 2 + 1 for every 1500 m^2 (or part of).

Note: Qualifying floor areas, as defined for fire service vehicle access.

Minimum distance of firefighting lift shaft to any part of a floor is 60 m. Hydrant outlets should be located in the firefighting lobby.



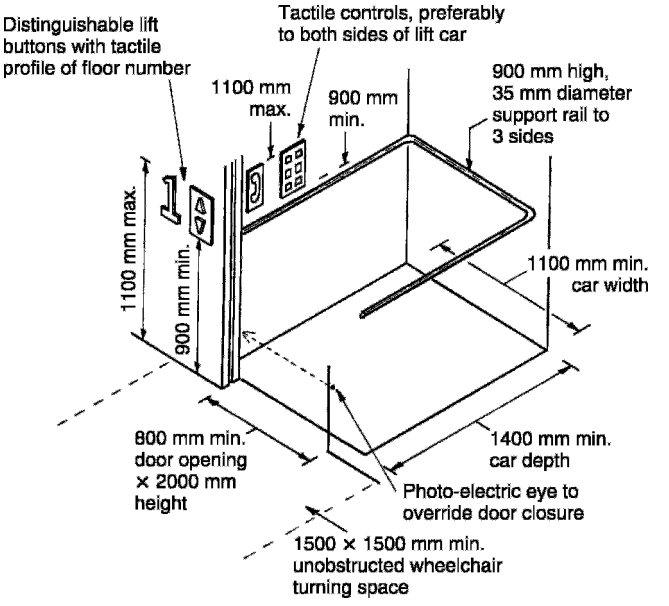
Firefighting lift in shared shaft

Refs: Building Regulations, Approved Document B5, Section 18: Access to buildings for fire-fighting personnel.

BS 5588-5: Fire precautions in the design, construction and use of buildings. Access and facilities for fire-fighting.

A passenger lift is the most suitable means for conveying wheelchair occupants between floor levels. However, a platform lift (BS 6440: Powered lifting platforms for use by disabled persons. Code of practice) or a platform stair lift (BS 5776: Specification for powered stairlifts) may be used if access is only between two levels. Platform lifts must not be used where they would obstruct a designated means of fire escape on a stairway.

Lift provisions:



- Landing space in front of lift doors should be sufficient to allow a wheelchair to turn and reverse into a lift car.
- Control/call panel should be prominent and easily distinguishable from its background.
- Time delay on door opening to be sufficient to allow wheelchair access. Doors fitted with a reactivation device to prevent people and/or wheelchair from being trapped in closing doors.
- Control panel in lift car positioned on a side wall, at least 400 mm from a corner at a height accessible whilst seated.
- Control panel floor numbers to be raised on buttons to assist the visually impaired.
- Audible announcement of the floor levels served to help people with visual difficulties.
- Visual display of floor levels served to assist people with hearing impairments.
- Emergency telephones to be provided with inductive couplers for the benefit of hearing aid users. Location at an accessible height from a wheelchair.
- Alarm controls provided at an accessible height with a visual display to confirm the bell has responded for the benefit of lift users with hearing difficulties.

Builder's work – machine room:

- Door and window openings sealed against the weather.
- Lockable and safe access for lift engineers and building facilities manager.
- Provide and secure a trapdoor to raise and lower machinery.
- Secure all non-structural floors, decking and temporary scaffolding in position.
- Temporary guards and ladders to be secured in position.
- Dimensions to the requirements of BS 5655 or lift manufacturer's specification.
- Provide reinforced concrete floor and plinths to include at least nine rope holes.
- Treat floor to prevent dust.
- Provide lifting beam(s) and pad stone support in adjacent walls.
- Heating and ventilation to ensure a controlled temperature between 4°C and 40°C.

Electrical work:

- Reduced voltage temporary lighting and power supplies for portable tools during construction.
- Main switch fuse for each lift at the supply company's intake.
- Run power mains from intake to the motor room and terminate with isolating switches.
- Lighting and 13 amp power supply in the machine room.
- Independent light supply from the intake to the lift car with control switchgear in the machine room or half way down the well.
- Lighting to the pit with a switch control in the lowest floor entrance.
- Permanent lighting in the well to consist of one lamp situated 500 mm maximum from the highest and lowest points with intermediate lamps at 7 m maximum spacing.

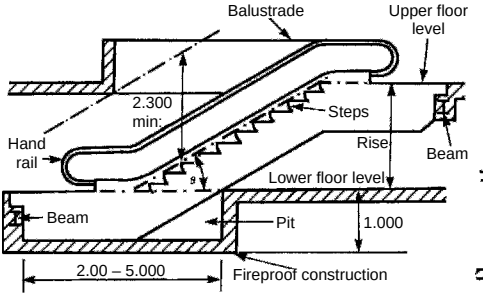
Builder's work – lift well:

- Calculations with regard to the architect's plans and structural loadings.
- Form a plumb lift well and pit according to the architect's drawings and to tolerances acceptable to the lift manufacturer (known as Nominal Minimum Plumb – the basic figures in which the lift equipment can be accommodated).
- Minimum thickness of enclosing walls – 230 mm brickwork or 130 mm reinforced concrete.
- Applying waterproofing or tanking to the pit and well as required.
- Paint surfaces to provide a dust-free finish.
- Provide dividing beams for multiple wells and inter-well pit screens. In a common well, a rigid screen extending at least 2·5 m above the lowest landing served and a full depth of the well between adjacent lifts.
- Secure lift manufacturer's car guides to lift well walls.
- Make door opening surrounds as specified and secure one above the other.
- Build or cast in inserts to secure lift manufacturer's door sills.
- Perform all necessary cutting away and making good for landing call buttons, door and gate locks, etc.
- Provide smoke vents of at least 0·1 m^2 free area per lift at the top of the shaft.
- Apply finishing coat of paintwork, to all exposed steelwork.
- Provide temporary guards for openings in the well.
- Supply and install temporary scaffolding and ladders to lift manufacturer's requirements.
- Offload and store materials, accessories, tools and clothing in a secure, dry and illuminated place protected from damage and theft.
- Provide mess rooms, sanitary accommodation and other welfare facilities in accordance with the Construction (Health, Safety and Welfare) Regulations.
- Provide access, trucking and cranage for equipment deliveries.

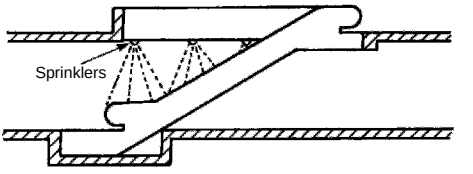
Escalators are moving stairs used to convey people between floor levels. They are usually arranged in pairs for opposing directional travel to transport up to 12 000 persons per hour between them.

The maximum carrying capacity depends on the step width and conveyor speed. Standard steps widths are 600, 800 and 1000 mm, with speeds of 0·5 and 0·65 m/s. Control gear is less complex than that required for lifts as the motor runs continuously with less load variations. In high rise buildings space for an escalator is unjustified for the full height and the high speed of modern lifts provides for a better service.

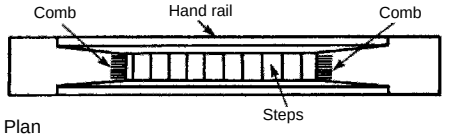
To prevent the exposed openings facilitating fire spread, a water sprinkler installation (see Part 12) can be used to automatically produce a curtain of water over the well. An alternative is a fireproof shutter actuated from a smoke detector or fusible links.



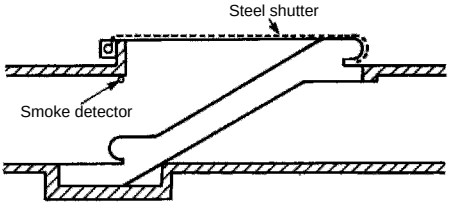
Elevation



Water curtain



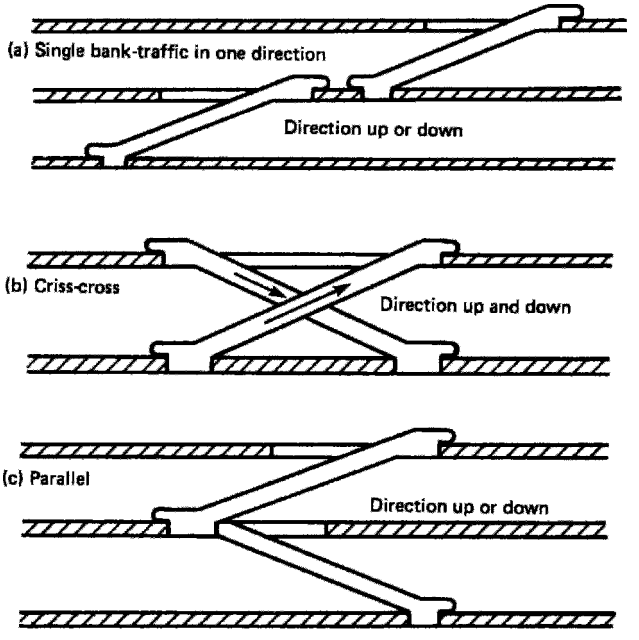
Plan



Fireproof sliding shutter

Escalator configurations vary depending on the required level of service. The one-directional single bank avoids interruption of traffic, but occupies more floor space than other arrangements.

A criss-cross or cross-over arrangement is used for moving traffic in both directions.



Escalator arrangements

Escalator capacity formula to estimate the number of persons (N) moved per hour:

$$N = \frac{3600 \times P \times V \times \text{cosine}\,\theta}{L}$$

where: P = number of persons per step
V = speed of travel (m/s)
θ = angle of incline
L = length of each step (m).

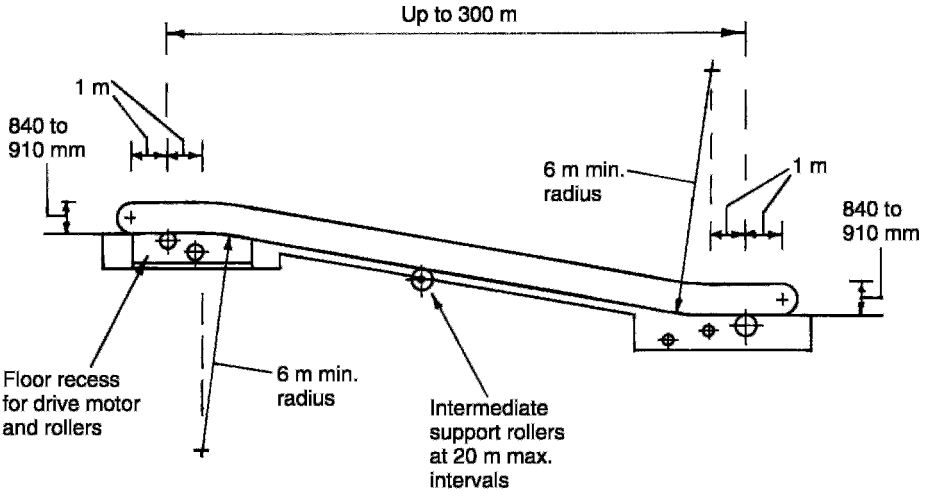
E.g. an escalator inclined at 35°, operating with one person per 400 mm step at 0·65 m/s.

$$N = \frac{3600 \times 1 \times 0{\cdot}65 \times 0{\cdot}8192}{0{\cdot}4} = 4792 \text{ persons per hour}$$

Travelators – also known as autowalks, passenger conveyors and moving pavements. They provide horizontal conveyance for people, prams, luggage trolleys, wheelchairs and small vehicles for distances up to about 300 metres. Slight inclines of up to 12° are also possible, with some as great as 18°, but these steeper pitches are not recommended for use with wheeled transport.

Applications range from retail, commercial and store environments to exhibition centres, railway and airport terminals. Speeds range between 0·6 and 1·3 m/s, any faster would prove difficult for entry and exit. When added to walking pace, the overall speed is about 2·5 m/s.

There have been a number of experiments with different materials for the conveyor surface. These have ranged from elastics, rubbers, composites, interlaced steel plates and trellised steel. The latter two have been the most successful in deviating from a straight line, but research continues, particularly into possibilities for variable speed lanes of up to 5 m/s. However, there could be a danger if bunching were to occur at the exit point.

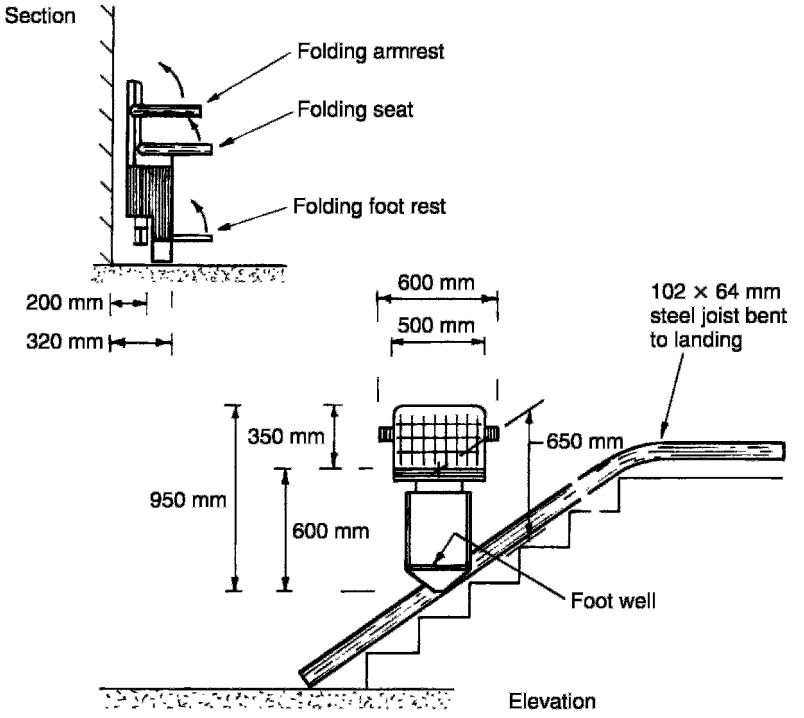


Capacity 6500 to 10 800 persons per hour

Typical inclined travelator

Stair lifts have been used in hospitals, homes for the elderly and convalescent homes for some time. In more recent years, manufacturers have recognised the domestic need and have produced simple applications which run on a standard steel joist bracketed to the adjacent wall. Development of Part M to the Building Regulations, `Access to and use of buildings', provides that staircases in all future dwellings are designed with the facility to accommodate and support a stair lift or a wheelchair lift. This will allow people to enjoy the home of their choice, without being forced to seek alternative accommodation.

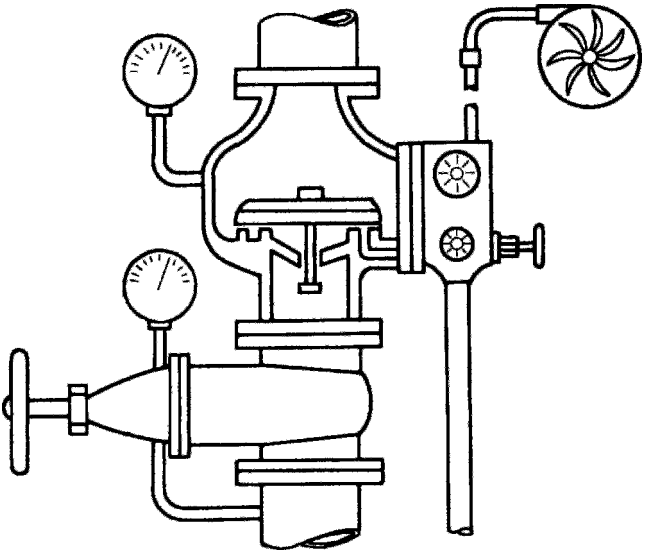
Standard 230 volt single-phase a.c. domestic electrical supply is adequate to power a stair lift at a speed of about 0·15 m/s. A 24 volt d.c. transformed low-voltage supply is used for push button controls. Features include overspeed brake, safety belt, optional swivel seat, folding seat and armrests and a manual lowering device. The angle of support rail inclination is usually within the range of 22°–50° within a maximum travel distance of about 20 m.



Typical domestic stair lift (dimensions approximate)

Ref: BS 5776: Specification for powered stair lifts.

12 FIRE PREVENTION AND CONTROL SERVICES



SPRINKLER SYSTEMS
SPRINKLERS, APPLICATION AND DESIGN
DRENCHERS
HOSE REELS
HYDRANTS
FOAM INSTALLATIONS
GAS EXTINGUISHERS
FIRE ALARMS
SMOKE, FIRE AND HEAT DETECTORS
ELECTRICAL ALARM CIRCUITS
FIRE DAMPERS IN DUCTWORK
PRESSURISATION OF ESCAPE ROUTES
SMOKE EXTRACTION, VENTILATION AND CONTROL
PORTABLE FIRE EXTINGUISHERS

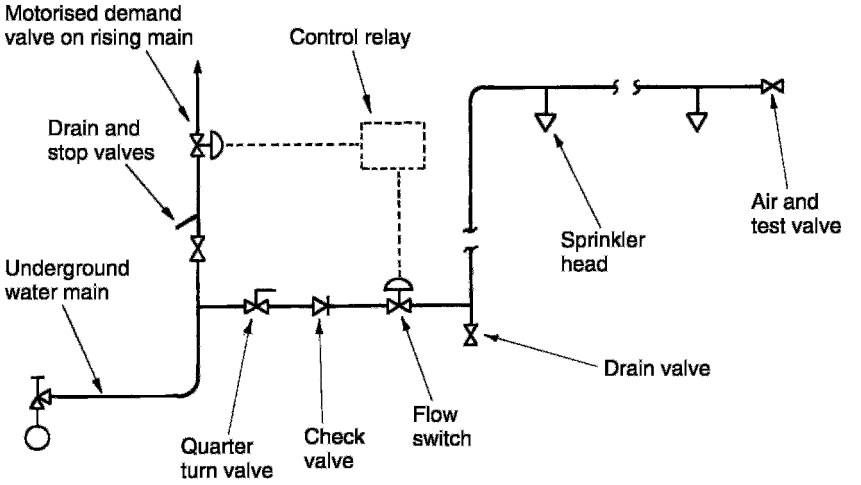
Water sprinklers provide an automatic spray dedicated to the area of fire outbreak. Sprinkler heads have temperature sensitive elements that respond immediately to heat, discharging the contents of the water main to which they are attached. In addition to a rapid response which reduces and isolates fire damage, sprinklers use less water to control a fire than the firefighting service, therefore preventing further damage from excess water.

Sprinkler systems were initially credited to an American, Henry Parmalee, following his research during the late 1800s. The idea was developed further by another American, Frederick Grinnell, and the name 'Grinnell' is still associated with the glass-type fusible element sprinkler head.

Domestic pipework – solvent cement bonded, post-chlorinated polyvinyl chloride (CPVC).

Industrial and commercial pipework – threaded galvanised mild steel.

The simplest application is to attach and suspend sprinkler heads from a water main fixed at ceiling level. However, some means of regulation and control is needed and this is shown in the domestic application indicated below.



Typical domestic sprinkler installation
Note: When flow switch is activated, demand valve closes.

Ref: BS 5306: Fire extinguishing installations and equipment on premises, BS 5306-2: Specification for sprinkler systems. BS EN 12259: Fixed fire-fighting systems. Components for sprinkler and water spray systems.

Pipe materials – Copper tube – BS EN 1057
Post-chlorinated polyvinylchloride (CPVC)

System – mains supplied, wet.

Pipe sizes – 25 mm minimum i.d. incoming service to supply at least 60 l/min. through any one sprinkler head, or 42 l/min. through any two sprinkler heads operating simultaneously in the same room.

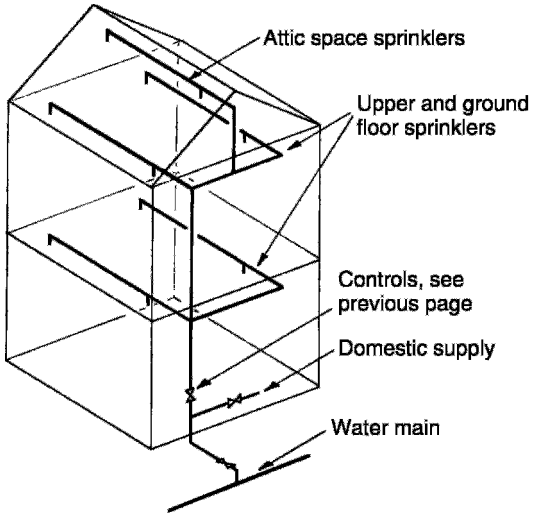
Sprinkler head spacing – area covered by one head, maximum 12 m^2.

Maximum distance between heads – 4 m.

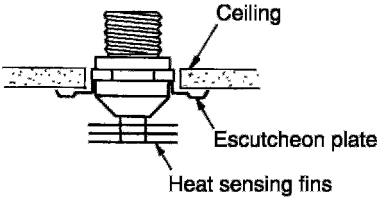
Maximum distance from wall to ceiling mounted head – 2 m.

Minimum distance between heads in the same room – 2 m (only 1 head per room is normal).

Operating pressure – Minimum 0.5 bar (50 kPa).



Typical domestic installation

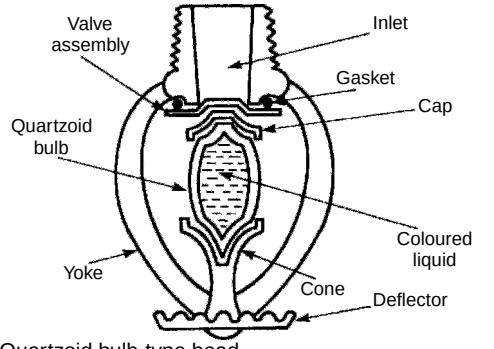


Fusible pellet pendent sprinkler head

Ref. BS 9251: Sprinkler systems for residential and domestic occupancies. Code of Practice.

Quartzoid bulb – a glass tube is used to retain a water valve on its seating. The bulb or tube contains a coloured volatile fluid, which when heated to a specific temperature expands to shatter the glass and open the valve. Water flows on to a deflector, dispersing as a spray over the source of fire. Operating temperatures vary with a colour coded liquid:

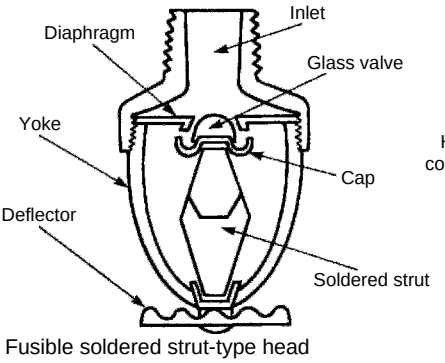
Orange – 57°C
Red – 68°C
Yellow – 79°C
Green – 93°C
Blue – 141°C
Mauve – 182°C
Black – 204 or 260°C



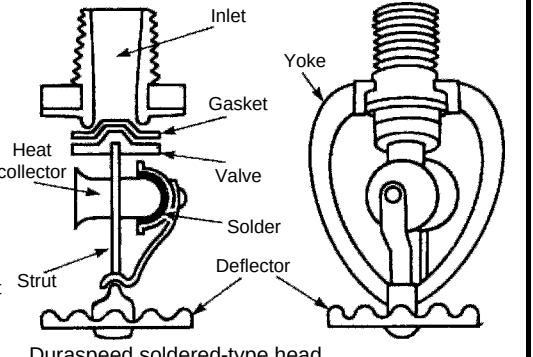
Quartzoid bulb-type head

Fusible strut – has two metal struts soldered together to retain a water valve in place. A range of solder melting temperatures are available to suit various applications. Under heat, the struts part to allow the valve to discharge water on the fire.

Duraspeed solder type – contains a heat collector which has a soldered cap attached. When heat melts the solder, the cap falls away to displace a strut allowing the head to open. Produced in a range of operating temperatures.



Fusible soldered strut-type head



Duraspeed soldered-type head

The specification of a sprinkler system will depend on the purpose intended for a building, its content, function, occupancy, size and disposition of rooms. Installations to commercial and industrial premises may be of the following type:

- Wet system – the simplest and most widely used application. The pipework is permanently charged with water. It is only suitable in premises, where temperatures remain above zero, although small sections of exposed pipework could be protected by trace element heating. The maximum number of sprinklers on one control valve is 1000. See page 469.
- Dry system – an air charged system applied to unheated premises such as warehousing, where winter temperatures could drop below zero. The maximum number of sprinklers on one control valve is 250, but this may increase to 500 if the air controls include an accelerator. See page 470.
- Alternative wet and dry system – essentially a wet system, but due to the slightly slower response time as air precedes water on discharge, the pipework is charged with water for most of the year and only air charged in winter. The maximum number of sprinklers is the same as a dry system. See page 470.
- Tail end system – used in a building with different internal functions, e.g. a mix of office accommodation with an unheated storage facility. The installation differs from an alternative wet and dry system, as most of the pipework is permanently charged with water. Only those pipes in parts of a building exposed to sub-zero temperatures are charged with air and these are designed as additions (tail ends) to a wet system. The wet and tail end parts are separated by a compressed air control valve. As the system is essentially wet, the maximum number of sprinklers may be 1000. The maximum number after a tail end air control valve is 100, with no more than 250 in total on tail end air valves in one installation.
- Pre-action system – used where there is a possibility that sprinkler heads may be accidently damaged by tall equipment or plant, e.g. a fork-lift truck. To avoid unnecessary water damage, the system is dry. If a sprinkler head is damaged, compressed air discharges and an initial alarm is activated. Water will only be supplied to the damaged sprinkler, if a ceiling mounted heat detector senses a temperature rise. The sensor will open a motorised valve on the water supply and effect another alarm. Detectors have a lower temperature rating than the sprinkler, therefore for a 68°C head, the detector will be set at about 60°C. Max. number of sprinklers is 1000.
- Recycling pre-action system – a variation of the pre-action system, designed as a damage limiting installation. After sprinklers have subdued a fire, a heat detector responds to a lower temperature and disengages the water supply after a 5-min. delay. If the fire restarts and temperature rises, the detector re-engages a motorised valve on the water supply. Maximum number of sprinklers is 1000.
- Cycling wet system – in principle similar to the recycling pre-action system except it is a normal wet system. It functions in conjunction with ceiling heat detectors which will disengage the water supply within a pre-determined time of the temperature dropping. If the temperature rises, the water supply will be automatically turned on again.

In addition to the considerations for system selection given on the preceding page, the building insurer will probably have greatest influence in determining the final specification. Insurer's requirements are likely to be formulated from guidance in:

- The Building Regulations, Approved Document B: Fire safety.
- BS EN 12845: Fixed fire fighting systems. Automatic sprinkler systems.
- The Loss Prevention Certification Board's Loss Prevention Standards.

The Loss Prevention Certification Board was formed in 1985 as an incorporation of the Fire Offices' Committee (FOC), the Fire Insurers' Research and Testing Organisation and the Fire Protection Association. Rules for design and installation originally produced by the FOC are now included in the British Standard.

Buildings are assessed by fire risk and categorised by fire load* as a hazard according to their purpose and content:

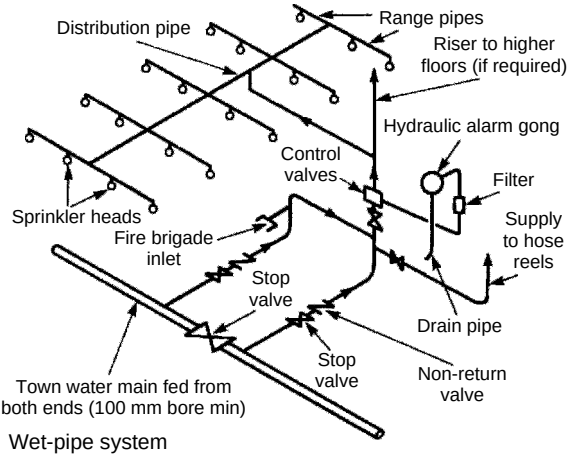
- Light hazard (LH) – low fire load and containing no single compartment exceeding 126 m^2 floor area with fire resistance of at least 30 min. Examples include educational premises, prisons and offices. Maximum protected area is 10 000 m^2 per control valve.
- Ordinary hazard (OH 1 to OH 4) – medium fire load category such as process or manufacturing premises.
  OH 1 – cement works, sheet metal processors, dairies, abattoirs, hospitals, hotels, offices, schools and restaurants.
  OH 2 – garages (car workshops), laboratories, bakeries, food processors, breweries, car parks and museums.
  OH 3 and 4 – industrial processors and warehouses with combustible stored products.
- High hazard – high fire load categories typical of warehouses containing combustible products in high racking systems. Fireworks factories and some chemical processes will also be included.

Note: Where specified, sprinklers should be installed in all parts of a building. Some exception may be permitted for toilets, washrooms and enclosed stairways.

*Fire load – an assessment of the combustible potential of materials contained within a building. Fire load is expressed as the heat potential per unit area, as a calorific value in Joules/m^2.

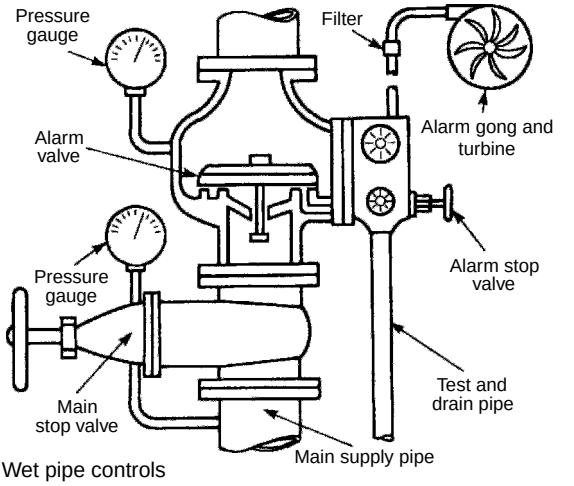
Grade 1 (low) – 1150 MJ/m^2, e.g. hotels, hospitals, schools, public libraries, offices, flats, restaurants, museums, sports centres and institutions.
Grade 2 (moderate) – 1150–2300 MJ/m^2, e.g. retail premises, factories and workshops.
Grade 3 (high) – 2300–4600 MJ/m^2, workshops, manufacturing processes and warehousing where combustible materials are deployed, e.g. timber and paper fabrication.

The wet system is used in heated buildings where there is no risk of the water in the pipework freezing. All pipework is permanently pressure charged with water and the sprinkler heads usually attach to the underside of the range pipes. Where water is mains supplied, it should be fed from both ends. If the main is under repair on one side, the stop valve and branch pipe can be closed and the sprinkler system supplied from the other branch pipe.



Wet-pipe system

When a sprinkler head is fractured water is immediately dispersed. Water will also flow through an annular groove in the alarm valve seating to a pipe connected to an alarm gong and turbine. A jet of water propels the turbine blades causing the alarm gong to operate. Pipeline flow switches will alert the local fire service in addition to operating an internal alarm system. Except under supervised maintenance, the main stop valve is padlocked in the open position.



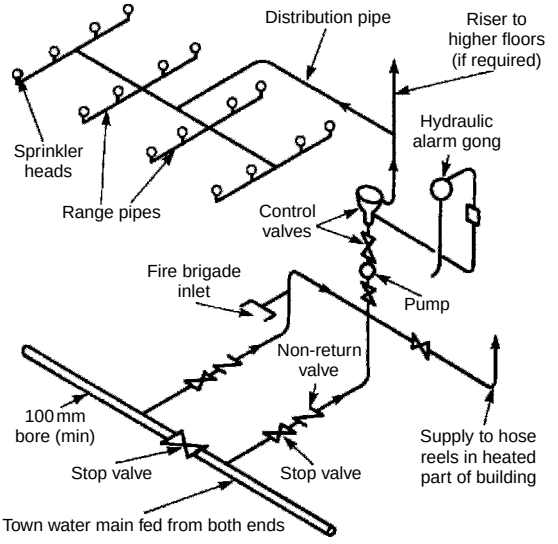
Wet pipe controls

Dry or an alternate wet-and-dry sprinkler system may be used in buildings that are unheated.

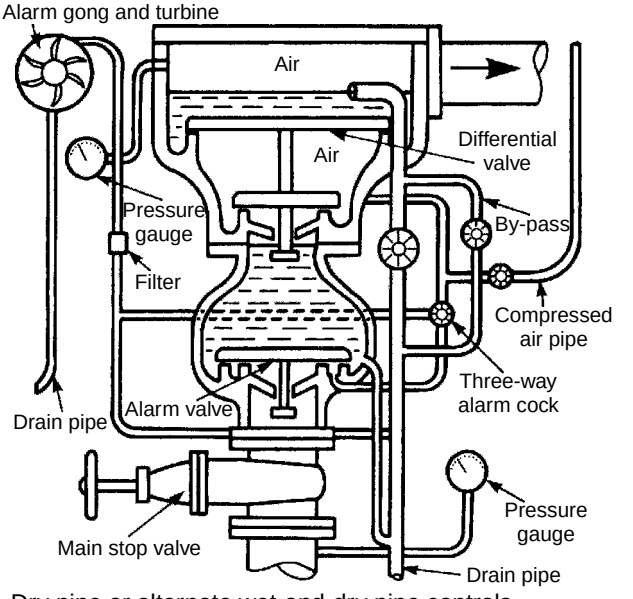
Dry system – installation pipework above the differential valve is permanently charged with compressed air. When a fire fractures a sprinkler head, the compressed air escapes to allow the retained water to displace the differential valve and flow to the broken sprinkler.

Alternate wet-and-dry system – a wet system for most of the year, but during the winter months it functions as a dry system.

The dry part of the system above the diaphragm or differential valve is charged with compressed air at about 200 kPa. Any loss of pressure is automatically replenished by a small compressor, but this will not interfere with water flow if the system is activated. When a sprinkler is fractured, an automatic booster pump can be used to rapidly exhaust the air and improve water flow. Sprinkler heads are fitted above the range pipes which are slightly inclined to allow the system to be fully drained.

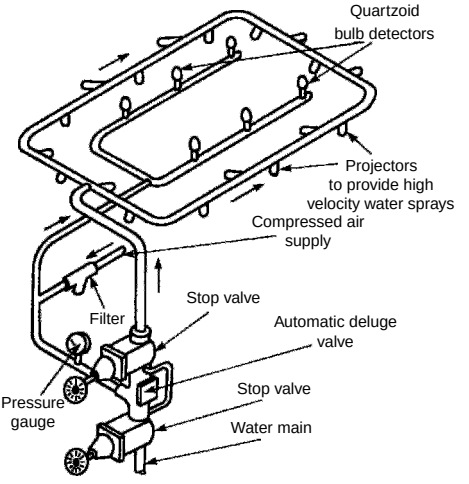


Dry pipe or alternate wet-and-dry pipe system



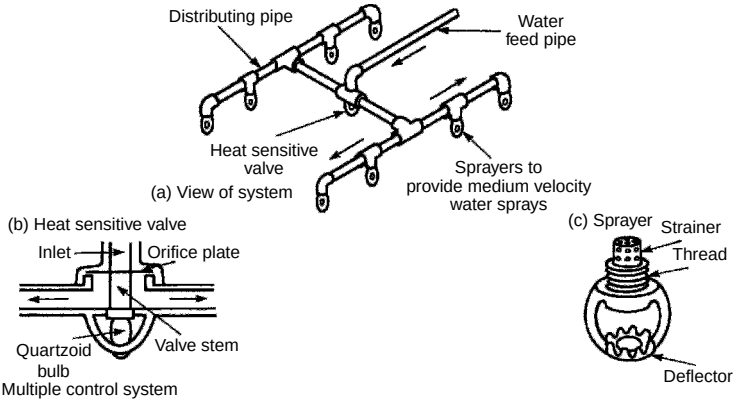
Dry pipe or alternate wet-and-dry pipe controls

Deluge system – used for specifically high fire hazards such as plastic foam manufacture, fireworks factories, aircraft hangars, etc., where there is a risk of intensive fire with a very fast rate of propagation. The pipework is in two parts, compressed air with quartzoid bulbs attached and a dry pipe with open ended spray projectors. When a fire occurs, the quartzoid bulbs shatter and compressed air in the pipeline is released allowing a diaphragm inside the deluge control valve to open and discharge water through the open pipe to the projectors.



Deluge system

Multiple control system – a heat sensitive sealed valve controls the flow of water to a small group of open sprayers attached to a dry pipe. When a fire occurs, the valve quartzoid bulb shatters allowing the previously retained water to displace the valve stem and flow to the sprayers. An alternative to a heat sensitive valve is a motorised valve activated by a smoke or fire detector.



Multiple control system

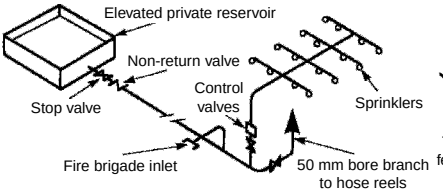
There are various sources of water supply that may be used for sprinkler applications.

Elevated private reservoir – minimum volume varies between 9 m^3 and 875 m^3 depending on the size of installation served.

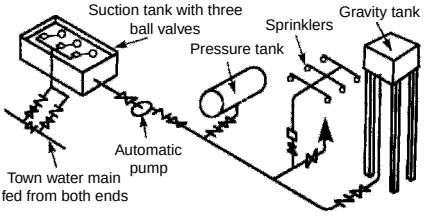
Suction tank – supplied from a water main. Minimum tank volume is between 2·5 m^3 and 585 m^3. A better standard of service may be achieved by combining the suction tank with a pressure tank, a gravity tank or an elevated private reservoir. A pressure tank must have a minimum volume of water between 7 m^3 and 23 m^3. A pressure switch or flow switch automatically engages the pump when the sprinklers open.

Gravity tank – usually located on a tower to provide sufficient head or water pressure above the sprinkler installation.

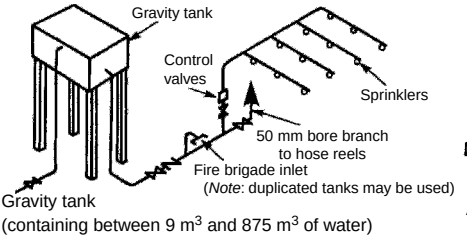
River or canal – strainers must be fitted on the lowest part of the suction pipes corresponding with the lowest water level. Duplicate pumps and pipes are required, one diesel and the other electrically powered.

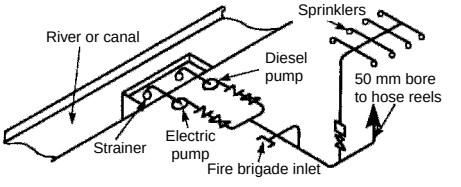


Elevated private reservoir



Town main suction tank automatic pump with pressure tank or gravity tank (if required)





Automatic pumps drawing from river or canal

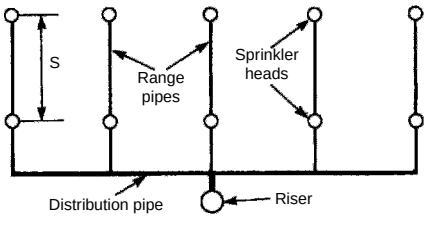
Note: Water source capacities, pressures, delivery rates, etc. vary with application. See tables in BS 5306-2 for specific situations.

The arrangement of pipework will depend on the building shape and layout, the position of the riser pipe and the number of sprinkler heads required. To provide a reasonably balanced distribution, it is preferable to have a centre feed pipe. In practice this is not always possible and end feed arrangements are used. The maximum spacing of sprinkler heads (S) on range pipes depends on the fire hazard classification of the building.

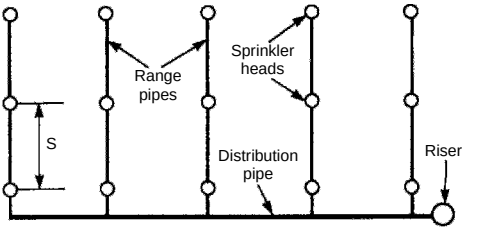
Hazard category	Max. spacing (S) of sprinkler heads (m)	Max. floor area covered by one sprinkler head (m^2)
Light	4·6	21
Ordinary	4·0 (standard)	12
	4·6 (staggered)*	12
High	3·7	9

* See next page

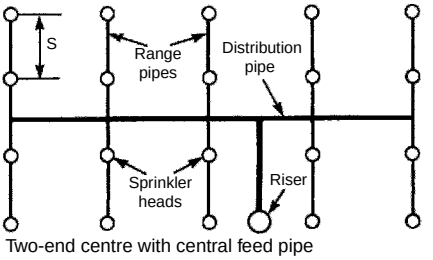
For sidewall-mounted sprinklers, the maximum floor area coverage by one sprinkler head is 17 m^2 for light hazard and 9 m^2 for ordinary hazard.



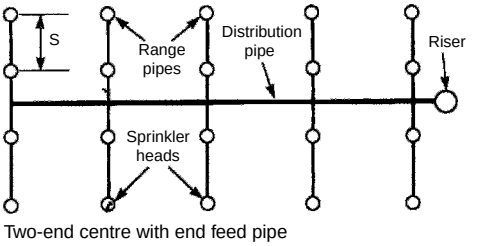
Two-end side with centre feed pipe



Three-end side with end feed pipe

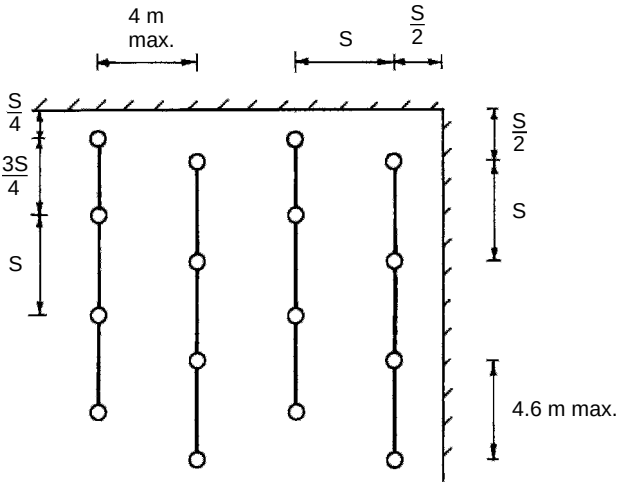


Two-end centre with central feed pipe



Two-end centre with end feed pipe

Staggered arrangement of sprinkler heads on an ordinary hazard installation:



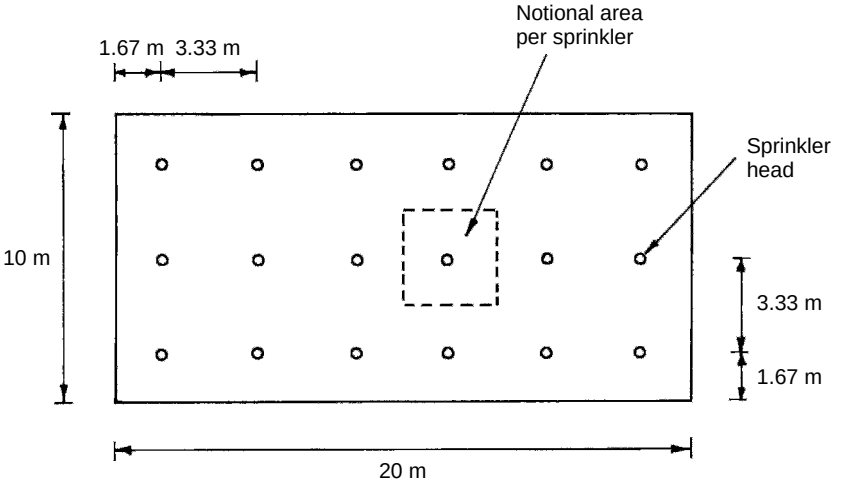
Calculating the number of sprinkler heads: e.g. an ordinary fire hazard category for a factory having a floor area 20 m × 10 m.

$$20 \times 10 = 200 \text{ m}^2.$$

Ordinary hazard requires a maximum served floor area of 12 m^2 per sprinkler head.

Therefore: 200 ÷ 12 = 16·67, i.e. at least 17 sprinkler heads.

For practical purposes, 18 could be installed as shown:



The maximum area served by each sprinkler head = 3·33 m × 3·33 m = 11·1 m^2.

This is satisfactory, being less than 12 m^2.

Sprinkler pipe installations downstream of the alarm and control valves should be sized by hydraulic calculation, with regard to system pressure and friction losses (see Part 1).

Tabulated data for pipe sizing is available in BS EN 12845 and design guides published by the Chartered Institution of Building Services Engineers. It is also possible to determine pipe diameters from the Hazen–Williams friction loss formula:

$$p = \frac{6{\cdot}05 \times 10^5 \times L \times Q^{1{\cdot}85}}{C^{1{\cdot}85} \times d^{4{\cdot}87}}$$

Where, p = pressure loss in pipe (bar)
L = equivalent length of pipework plus bends and fittings, i.e. effective pipe length (m)
Q = flow rate through the pipe (minimum 60 litres/minute)
C = constant for pipe material (see table)
d = pipe internal diameter (mm)

Pipe material	Constant (C)
Cast iron	100
Steel	120
Stainless steel	140
Copper	140
CPVC	150

Maximum water velocity through valves is 6 m/s. Through any other part of the system, 10 m/s.

By determining an acceptable pressure loss as a design prerequisite, the Hazen–Williams formula can be rearranged with the pipe diameter as the subject:

$$d = \sqrt[4{\cdot}87]{\frac{6{\cdot}05 \times 10^5 \times L \times Q^{1{\cdot}85}}{C^{1{\cdot}85} \times p}}$$

e.g. Calculate the diameter of 30 m effective length steel pipe, where the acceptable pressure loss is 0·02 bar with a water flow rate of 60 litres/minute.

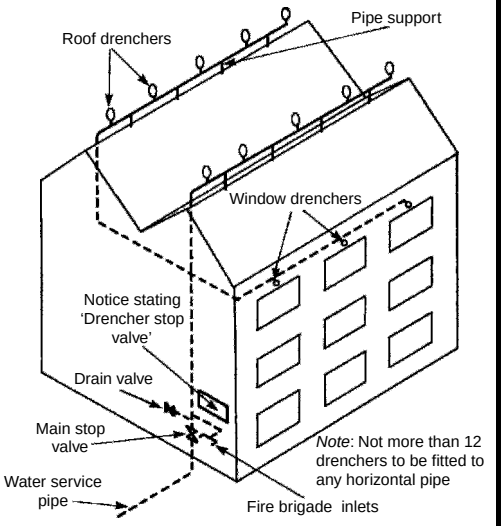
$$d = \sqrt[4{\cdot}87]{\frac{6{\cdot}05 \times 10^5 \times 30 \times 60^{1{\cdot}85}}{120^{1{\cdot}85} \times 0{\cdot}02}}$$

$$d = \sqrt[4{\cdot}87]{\frac{353554{\cdot}56 \times 10^5}{140{\cdot}45}} = 53{\cdot}09 \text{ mm (i.d.)}$$

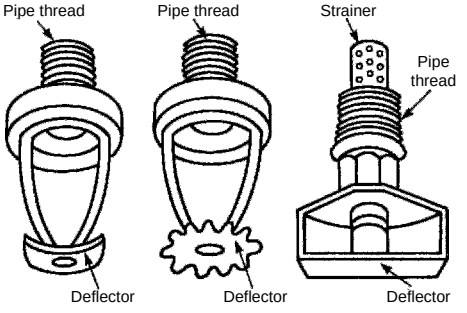
50 mm nominal inside diameter is just too small, therefore a 65 mm nominal inside diameter steel pipe would be selected.

Drenchers

A drencher fire control system provides a discharge of water over roofs, walls and windows to prevent fire spreading from or to adjacent buildings. Automatic drenchers are similar in operating principle to individual quartzoid bulb sprinkler heads. A manually operated stop valve can also be used with dry pipes and open spray nozzles. This stop valve must be located in a prominent position with unimpeded access. Installation pipework should fall to a drain valve positioned at the lowest point above the stop valve. The number of drencher nozzles per pipe is similar to the arrangements for conventional sprinkler installations as indicated in BS 5306-2. For guidance, two drenchers can normally be supplied by a 25 mm i.d. pipe. A 50 mm i.d. pipe can supply ten drenchers, a 75 mm i.d. pipe 36 drenchers and a 150 mm i.d. pipe over 100 drenchers. An example of application is in theatres, where the drenchers may be fitted above the proscenium arch at the stage side to protect the safety curtain.

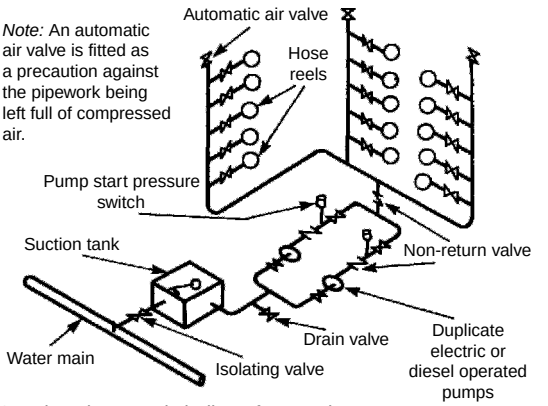


Typical drencher installation

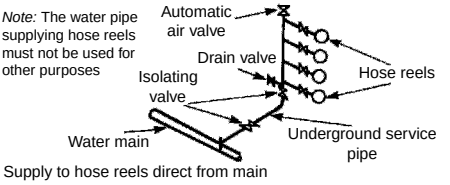


Types of drencher

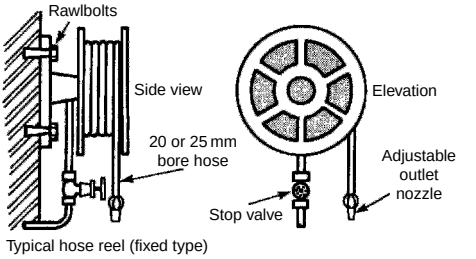
Hose reels are firefighting equipment for use as a first-aid measure by building occupants. They should be located where users are least likely to be endangered by the fire, i.e. the staircase landing. The hose most distant from the source of water should be capable of discharging 0·4 l/s at a 6 m distance from the nozzle, when the two most remote hose reels are operating simultaneously. A pressure of 200 kPa is required at the highest reel. If the water main cannot provide this, a break/suction tank and booster pumps should be installed. The tank must have a minimum volume of water of 1·6 m^3. A 50 mm i.d. supply pipe is adequate for buildings up to 15 m height and a 65 mm i.d. pipe will be sufficient for buildings greater than this. Fixed or swinging hose reels are located in wall recesses at a height of about 1 m above floor level. They are supplied by a 25 mm i.d. pipe to 20 or 25 mm i.d. reinforced non-kink rubber hose in lengths up to 45 m to cover 800 m^2 of floor area per installation.



Supply to hose reels indirect from main



Supply to hose reels direct from main

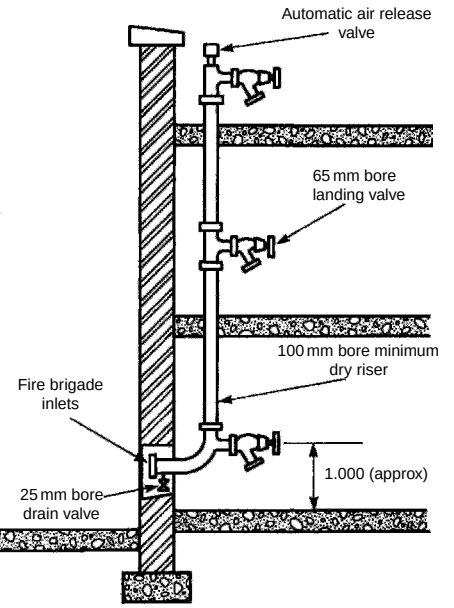


Typical hose reel (fixed type)

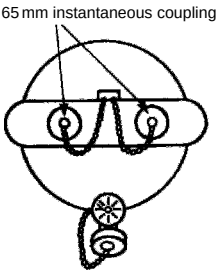
Ref: BS 5306: Fire extinguishing installations and equipment on premises, BS 5306-1: Hose reels and foam inlets.

A dry riser is in effect an empty vertical pipe which becomes a firefighter's hose extension to supply hydrants at each floor level. Risers should be disposed so that no part of the floor is more than 60 m from a landing valve. This distance is measured along a route suitable for a firefighting hose line, to include any dimension up or down a stairway. Buildings with floors up to 45 m above fire service vehicle access level require one 65 mm landing valve on each floor from a 100 mm i.d. riser. Buildings between 45 m and 60 m with one or two landing valves per floor require a 150 mm i.d. riser. For buildings above 60 m a wet riser must be installed. Two 65 mm i.d. inlet hose couplings are required for a 100 mm riser and four 65 mm i.d. inlets are required for a 150 mm riser. The riser must be electrically bonded to earth.

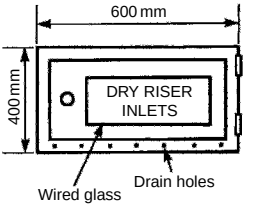
Note: A dry riser is installed either in unheated buildings or where the water main will not provide sufficient pressure at the highest landing valve. A hard standing for the Fire Service Vehicle is required at the base of the riser. One landing valve is required for every 900 m^2 of floor area.



Typical arrangement of a dry riser



(b) Front view of Fire Brigade inlets



Note: Door fitted with spring lock which opens when the glass is broken

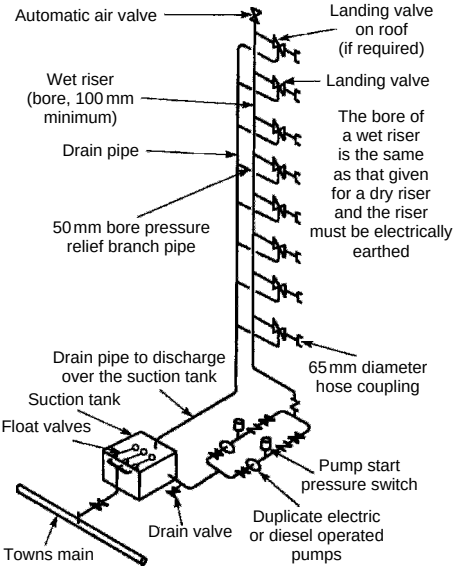
(b) Front view of Fire Brigade inlet box

Details of dry riser inlet

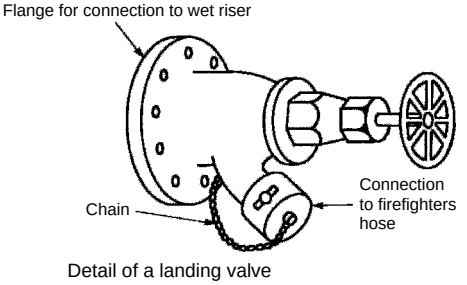
A wet riser is suitable in any building where hydrant installations are specified. It is essential in buildings where floor levels are higher than that served by a dry riser, i.e. greater than 60 m above fire service vehicle access level. A wet riser is constantly charged with water at a minimum running pressure of 400 kPa with up to three most remote landing valves operating simultaneously. A flow rate of 25 l/s is also required. The maximum pressure with one outlet open is 500 kPa to protect firefighting hoses from rupturing. Orifice plates may be fitted to the lower landing valves to restrict pressure. Alternatively, a pressure relief valve may be incorporated in the outlet of the landing valve. The discharge from this is conveyed in a 100 mm i.d. drain pipe.

To maintain water at the required pressure and delivery rate, it is usually necessary to install pumping equipment. Direct pumping from the main is unacceptable. A suction or break tank with a minimum water volume of 45 m^3 is used with duplicate power source service pumps. One 65 mm landing valve should be provided for every 900 m^2 floor area.

Note: In addition to the supply through the float valves the suction tank should also be supplied with a 150 mm Fire service inlet.



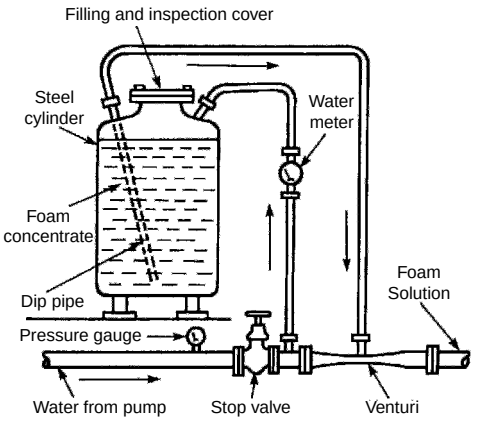
Typical arrangement of a wet riser



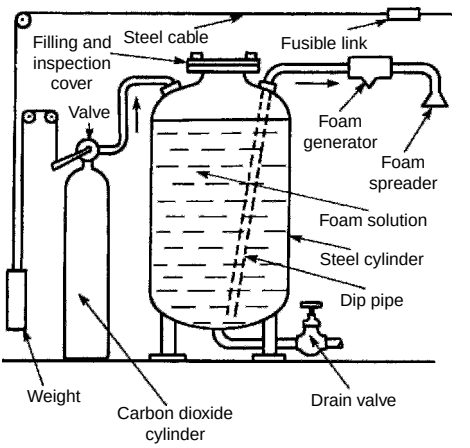
Detail of a landing valve

A pump operated mechanical foam installation consists of a foam concentrate tank located outside of the area to be protected. The tank has a water supply pipe inlet and foam pipe outlet. A venturi is fitted in the pipeline to draw the foam out of the tank. When the water pump is switched on, the venturi effect causes a reduction in pressure at the foam pipe connection, resulting in a mixture of foam concentrate and water discharging through the outlet pipe.

A pre-mixed foam installation consists of a storage tank containing foam solution. When a fire occurs in the protected area, a fusible link is broken to release a weight which falls to open a valve on the carbon dioxide cylinder. Foam solution is forced out of the tank at a pressure of about 1000 kPa to discharge over the protected equipment, e.g. an oil tank.

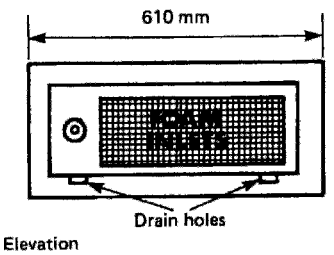


Pump operated mechanical foam installation

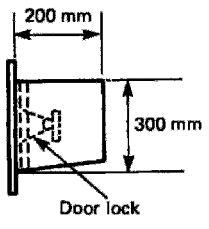


Pre-mixed foam installation

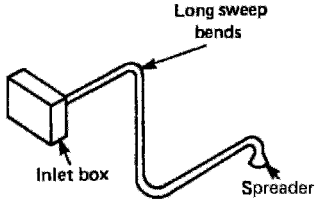
A foam installation is used for application from remote points on to flammable liquid fire risks. This type of installation is often used with oil-fired boilers and oil storage tanks. A foam access box is built into the wall at an easily accessible place for fire-fighters to attach hoses from their foam generating and mixing equipment. The box is usually located about 600 mm above adjacent ground and should be clear of any openings through which heat, smoke or flames can pass. The glass fronted box can be broken and the lock released from inside. Two 65 mm diameter inlets may be used. A 65 or 75 mm i.d. galvanised steel pipe is normally used for the distribution. A maximum pipework length of 18 m is recommended and this must slope slightly towards the spreaders. Vertical drop pipes are acceptable but vertically inclined pipes must not be used. Spreader terminals are positioned about 1 m above oil burners and about 150 mm above oil spill level of stored fuel.

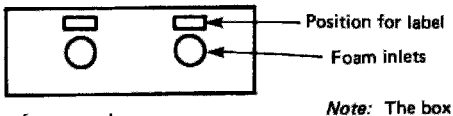


Elevation



Side view





View of rear panel

Foam inlet box

Note: The box has a glass front which may be broken in an emergency

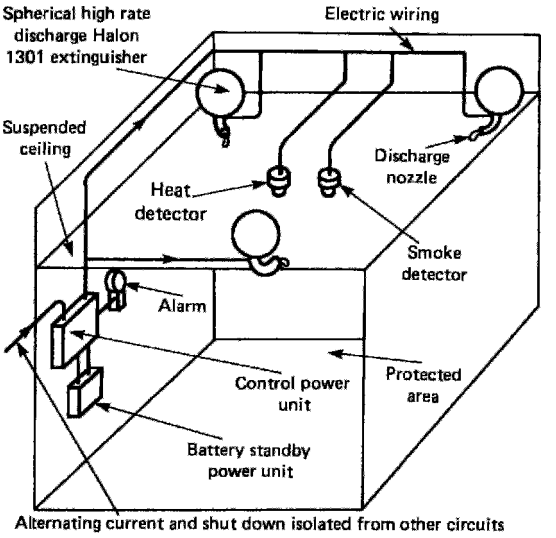


Foam pipe systems

Ref: BS 5306: Fire extinguishing installations and equipment on premises, BS 5306-6: Foam systems.

The majority of gas extinguishing systems have been either halon 1301 or carbon dioxide (see next page). Halons are electrically non-conductive and safe to use where personnel remain in an area of gas discharge. They are also more effective than carbon dioxide, being five times the density of air, whilst carbon dioxide is only one-and-a-half times. Unfortunately halon or bromochlorodifluoromethane (BCF) gases are a hazard to the environment, by contributing significantly to the depleting effect of the ozone layer. In 1987 a meeting of major countries at a Montreal convention agreed to phase out the use of these gases by 2002. Therefore, except for systems installed in less co-operative countries, new installations will contain halon substitutes. These include inergen and argonite, both mixtures of nitrogen and argon, the former containing a small amount of carbon dioxide.

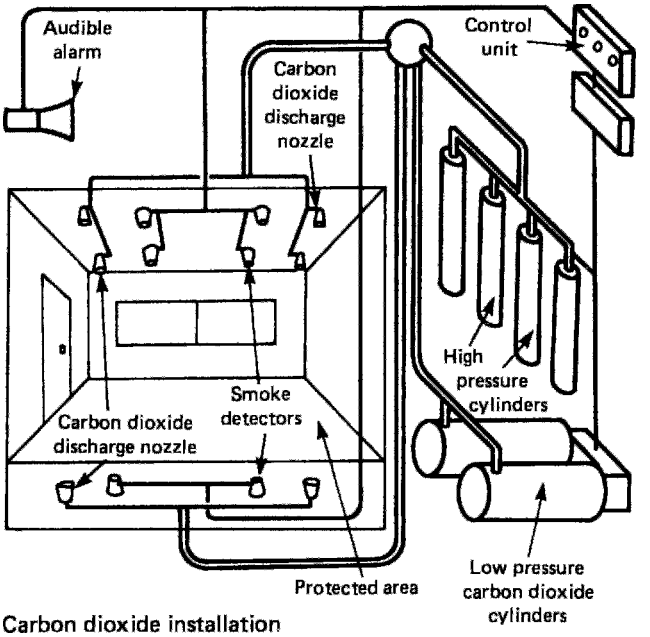
In principle, the systems are suitable where there is a high density of equipment, e.g. tape libraries and computer suites where an alternative wet system would be considered too damaging. Gas is stored in spherical steel containers which can be secured in a ceiling or floor void or against a wall. When activated by smoke or heat, detectors immediately open valves on the extinguishers to totally flood the protected area with a colourless and odourless gas.



Halon 1301 installation

Ref: BS 5306: Fire extinguishing installations and equipment on premises, BS 5306-5: Halon systems.

Carbon dioxide is an alternative to halon as a dry gas extinguisher. It has been used as an extinguishing agent for a considerable time, particularly in portable extinguishers. As the gas is dry and non-conductive it is ideal for containing fires from electrical equipment, in addition to textiles, machinery, petroleum and oil fires. Carbon dioxide is heavier than air and can flow around obstacles to effectively reduce the oxygen content of air from its normal 21% to about 15%. This considerably reduces an important component of the combustion process (see page 498). Integrated high and low pressure gas systems may be used, with the former operating at up to 5800 kPa. Systems can be either electrical, pneumatic or mechanical with a manual override facility. Carbon dioxide is potentially hazardous to personnel, therefore it is essential that the system is automatically locked off when the protected area is occupied. In these circumstances it can be switched to manual control. Air tightness of a protected room is essential for the success of this system as total flooding relies on gas containment by peripheral means.



Carbon dioxide installation

Ref: BS 5306: Fire extinguishing installations and equipment on premises, BS 5306-4: Specification for carbon dioxide systems.

Fire detection and alarm systems may contain:

- system control unit
- primary (mains) electrical supply
- secondary (battery or capacitor stand-by) power supply. An emergency generator could also be used
- alarm activation devices – manual or automatic
- alarm indication devices – audible and/or visual
- remote indication on a building monitoring system
- control relay via a building management system to effect fire extinguishers and ventilation smoke control actuators.

System control unit – an alarm panel which monitors the state of all parts (zones) of the installation. It identifies the point of origin of an alarm, displays this on the panel and communicates this to remote control locations.

Zones:

- Max. 2000 m^2 floor area in one storey.
- No detachment of compartment areas within one floor area zone.
- Max. 30 m search distance into a zone.
- Single occupancy of a zone where several separate business functions occur in one building.

Requirements for dwellings

Automatic fire detection and alarm systems are to be provided to the recommendations of BS 5839: Fire detection and alarm systems in buildings. They may comply with Part 1 or 6 of the BS, i.e. Code of practice for system design, installation, commissioning and maintenance, or Code of practice for the design and installation of fire detection and alarm systems in dwellings, respectively. Alternatively, a smoke alarm system is acceptable if it complies with BS 5446-1: Fire detection and fire alarm devices for dwellings. Specification for smoke alarms. These should have primary and secondary power supplies.

Point detectors – individual heat or smoke detection units which respond to an irregular situation in the immediate vicinity.

Line detectors – a continuous type of detection comprising a pair of conducting cables separated by low temperature melting insulation to permit a short circuit alarm when the cables contact. Suitable in tunnels and service shafts.

Provision in large houses:

Floor area	Storeys (inc. basement)	System
>200 m^2	>3	BS 5839-1, type L2
>200 m^2	⩽3	BS 5839-6, type LD3

Note: prefixes used in the BS types indicates that L is a specific application to protection of life, whereas P indicates that for property.

Application:

- Optical type (photo-electric) detectors in circulation spaces, i.e. hallways, corridors and landings.
- Ionisation type detectors in living and dining areas.

Preferred location of detectors:

- Over 300 mm from light fittings.
- Min. one per storey.
- Loft conversions, with alarm linked to operate others and be operated by others in the dwelling.
- Circulation spaces between bedrooms.
- Circulation spaces < 7.5 m from doors to habitable rooms.
- Kitchens (with regard to heat/smoke producing appliances).
- Living rooms.

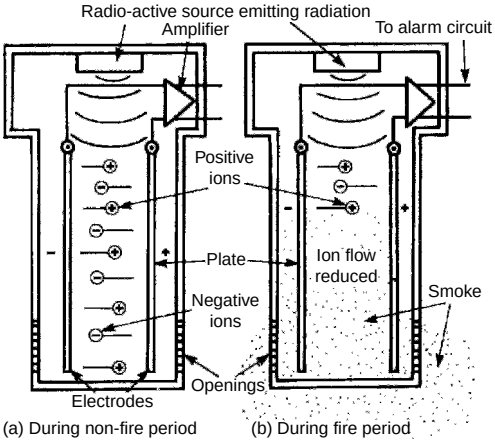
Requirements for buildings other than dwellings

This is less easy to define due to the variation in building types and patterns of occupancy. BS 5839 requirements may suit some buildings, but could cause panic in others, e.g. shopping centres, where people may be unfamiliar with the layout. In these situations, trained staff may be the preferred system of building evacuation. At building design stage, consultation between the local building control authority, the fire authority and the building's insurer is paramount, as alterations post-construction are always extremely expensive.

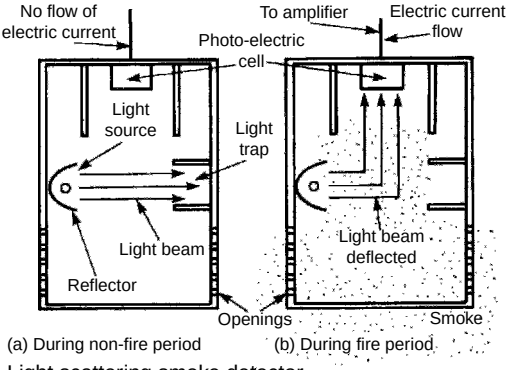
Ref. Building Regulations, Approved Document B: Fire safety.
Section B1: Means of warning and escape.

Ionisation smoke detector – positive and negative charged plate electrodes attract opposingly charged ions. An ion is an atom or a group of atoms which have lost or gained one or more electrons, to carry a predominantly positive or negative charge. The movement of ions between the plates reduces the resistance of air, such that a small electric current is produced. If smoke enters the unit, particles attach to the ions slowing their movement. This reduction in current flow actuates an electronic relay circuit to operate an alarm.

Light scattering smoke detector – a light beam projects onto a light trap into which it is absorbed. When smoke enters the detector, some of the light beam is deflected upwards onto a photo-electric cell. This light energises the cell to produce an electric current which activates the alarm relay.



Ionisation smoke detector



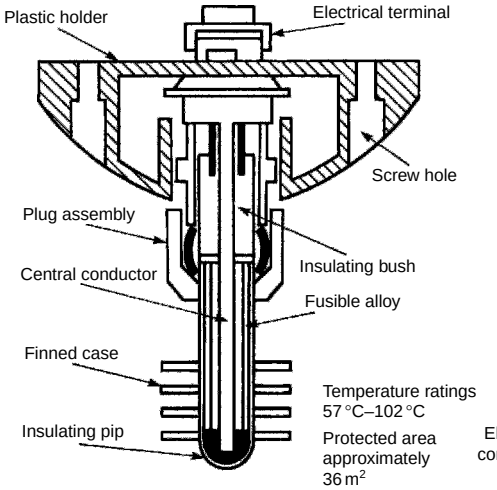
Light scattering smoke detector

Refs: BS 5446: Fire detection and fire alarm devices for dwellings.
BS 5446-1: Specification for smoke alarms.

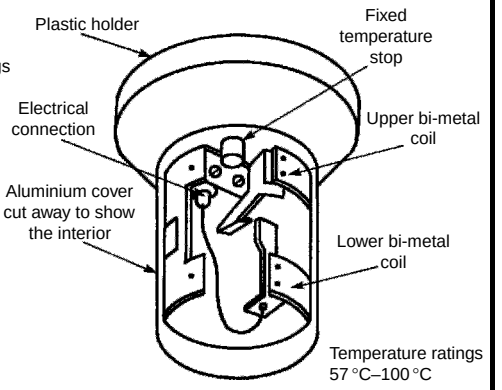
Heat detectors are used where smoking is permitted and in other situations where a smoke detector could be inadvertently actuated by process work in the building, e.g. a factory. Detectors are designed to identify a fire in its more advanced stage, so their response time is longer than smoke detectors.

Fusible type – has an alloy sensor with a thin walled casing fitted with heat collecting fins at its lower end. An electrical conductor passes through the centre. The casing has a fusible alloy lining and this functions as a second conductor. Heat melts the lining at a pre-determined temperature causing it to contact the central conductor and complete an alarm relay electrical circuit.

Bi-metallic coil type – heat passes through the cover to the bi-metal coils. Initially the lower coil receives greater heat than the upper coil. The lower coil responds by making contact with the upper coil to complete an electrical alarm circuit.



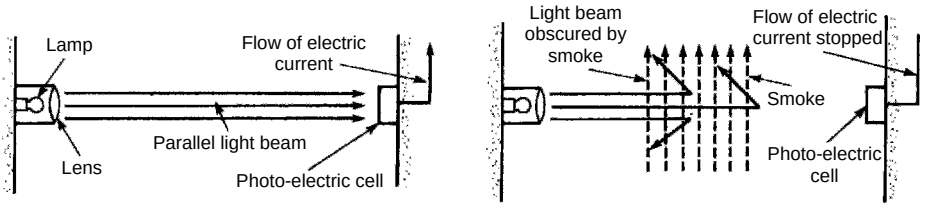
Fusible alloy heat detector



Bi-metal coil heat detector

Light obscuring – a beam of light is projected across the protected area close to the ceiling. The light falls onto a photo-electric cell which produces a small electrical current for amplification and application to an alarm circuit. Smoke rising from a fire passes through the light beam to obscure and interrupt the amount of light falling on the photo-electric cell. The flow of electric current from the cell reduces sufficiently to activate an alarm relay.

A variation is the light-scatter type. In normal use the light is widely dispersed and no light reaches the photo-electric cell receptor. In the presence of smoke, particulates deflect light on to the receptor to energise the cell.



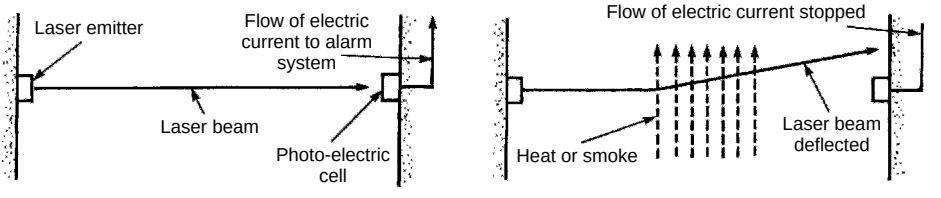
(a) Detector during non-fire period

(b) Detector during fire period

Note: The light beam will operate over a distance up to 15 m.

Light obscuring detector

Laser beam – a band of light which can be visible or infra-red projected onto a photo-electric cell. It does not fan out or diffuse as it travels through an uninterrupted atmosphere. The beam can operate effectively at distances up to 100 m. If a fire occurs, smoke and heat rises and the pulsating beam is deflected away from the cell or reduced in intensity. As the cell is de-energised, this effects on alarm relay.



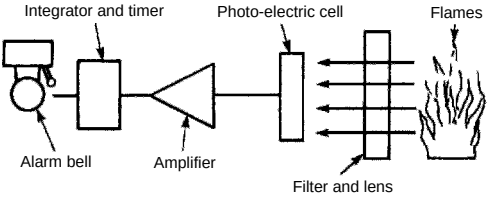
(a) Detector during non-fire period

(b) Detector during fire period

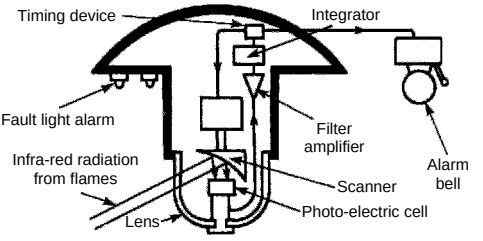
Laser beam detector

In addition to producing hot gases, fire also releases radiant energy in the form of visible light, infra-red and ultra-violet radiation. Radiant energy travels in waves from the fire.

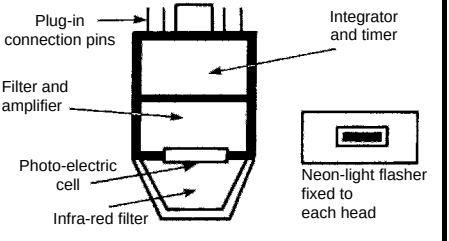
Infra-red detector – detectors have a selective filter and lens to allow only infra-red radiation to fall on a photo-electric cell. Flames have a distinctive flicker, normally in the range of 4 to 15 Hz. The filter is used to exclude signals outside of this range. The amplifier is used to increase the current from the photo-electric cell. To reduce false alarms, a timing device operates the alarm a few seconds after the outbreak of fire.



Components of an infra-red detector

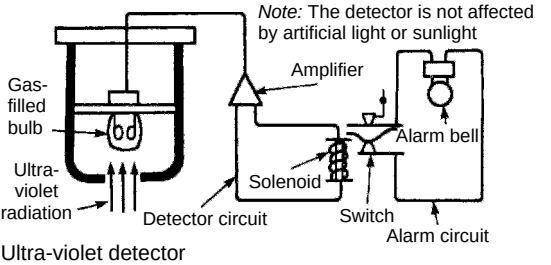


Infra-red detector for large areas



Infra-red detector for small areas

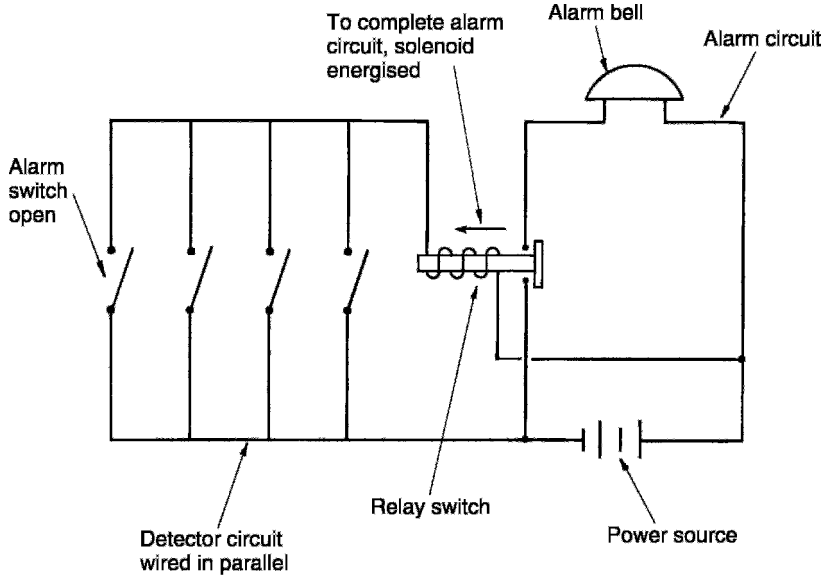
Ultra-violet detector – these detectors have a gas-filled bulb which reacts with ultra-violet radiation. When the bulb receives radiant energy, the gas is ionised to produce an electric current. When this current exceeds the set point of the amplifier the alarm circuit closes to operate the alarm system.



Ultra-violet detector

Fire alarm electrical circuits may be of the 'open' or 'closed' types. In addition to, or as an alternative to, automatic smoke or fire sensing switches, manual break-glass alarm switches can be wall mounted at about 1·5 m above floor level in lobbies, corridors and other common access locations. No person should have to travel more than 30 m to use an alarm. In large managed buildings, a sub-circuit will connect to the facilities manager's office or in more sophisticated situations the alarm can relay through telecommunications cables to a central controller and the fire service.

Open circuit – call points or detectors are connected to open switches, which prevent current flowing through the circuit when it is on stand-by. Closing a switch on the detector circuit actuates a solenoid (electromagnet) to complete the alarm circuit. As there is no current flow whilst on stand-by there is no electrical power consumption. The disadvantage of this system is that if part of the detector circuit is inadvertently damaged, some of the switches will not operate.

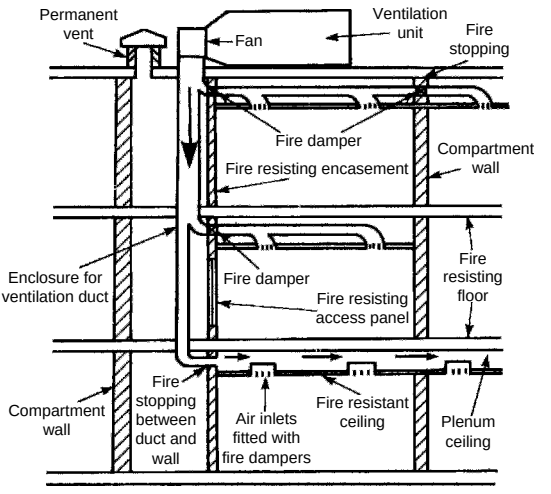


Open alarm circuit

Ventilation of services enclosures is required to dilute flammable, toxic or corrosive gases. This can be taken to include smoke and hot gases that will occur as a result of fire, particularly where the void contains combustible PVC cable sheathing and uPVC pipes. To provide a safe level of ventilation and to prevent overheating in a restricted enclosure, permanent natural ventilation should be at least 0·05 m^2 and 1/150 of the cross-sectional area for enclosure areas of less than 7·5 m^2 and greater than 7·5 m^2 respectively.

Openings and access panels into services enclosures should be minimal. The enclosure itself should be gas tight and there must be no access from a stairway. Where access panels or doors are provided they should be rated at not less than half the fire resistance of the structure, and have an integrity rating of at least 30 minutes (see BS 476-22). Fire doors should be fitted with self closers.

Where ventilation ducts pass from one compartment to another or into a services enclosure, the void made in the fire resisting construction must be made good with a suitable fire stopping material. Automatic fire dampers are also required in this situation to prevent fire spreading between compartments.

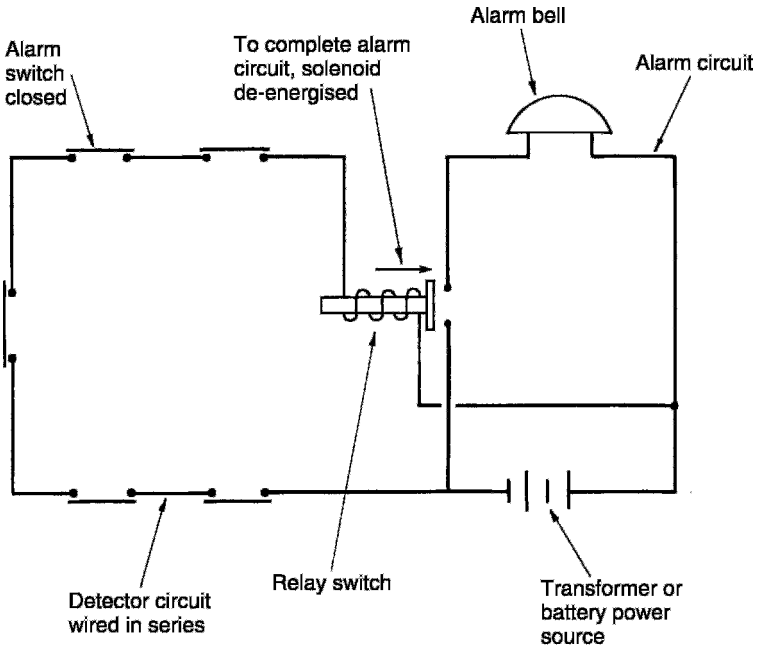


Installation of ventilating ductwork

Refs: BS 8313: Code of practice for accommodation of building services in ducts.
BS 5588-9: Code of practice for ventilation and air conditioning ductwork.
Building Regulations, Approved Document B3: Section 11, Protection of openings and fire-stopping.

Electrical Power to 'open' or 'closed' fire alarm circuits should be separate from any other electrical installation. To isolate it completely from any interruption to mains supply, it is usually transformed to 24-60 volts d.c. and provided with a battery back-up system in the event of the fire damaging the mains source of power.

Closed circuit - call points or detectors may be regarded as closed switches allowing current to flow in the detector circuit. This permanent current flow energises a solenoid switch which retains a break in the alarm circuit. When a detector circuit switch is operated, i.e. opened, the solenoid is de-energised allowing a spring mechanism to connect it across the alarm circuit terminals and effect the alarm.

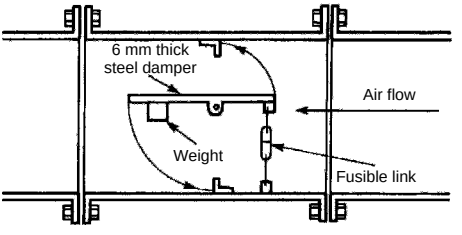


Closed alarm circuit

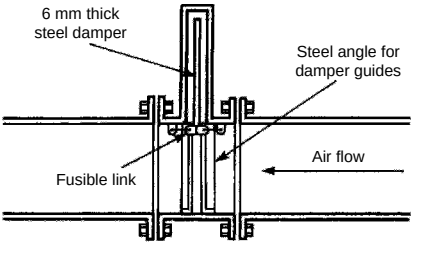
Ref: BS EN 54: Fire detection and fire alarm systems.

Fire dampers are required in ventilation and air conditioning systems to prevent smoke and fire spreading through the ductwork to other parts of the building. Dampers should be positioned to maintain continuity of compartmentation by structural division. They can operate automatically by fusible link melting at a pre-determined temperature of about 70°C, to release a steel shutter. An electro-magnet may also be used to retain the shutter in the open position. The electromagnet is deactivated to release the shutter by a relay circuit from a fire or smoke detector. The latter is preferable, as a considerable amount of smoke damage can occur before sufficient heat penetrates the ductwork to activate a heat detector or a fusible link.

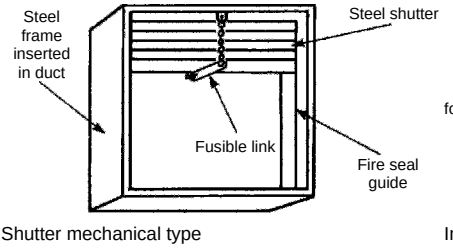
An intumescent-coated honeycomb damper is an alternative. In the presence of heat, the coating expands to about a hundred times its original volume to form sufficient mass to impair the movement of fire through the duct. This type of damper has limited fire resistance and is only likely to be specified in low velocity systems.



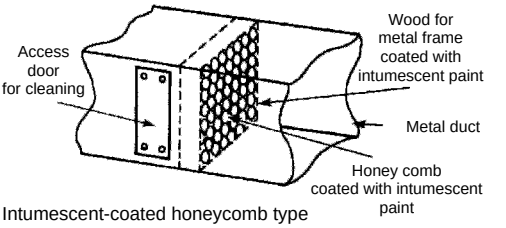
Swinging mechanical type



Sliding mechanical type



Shutter mechanical type

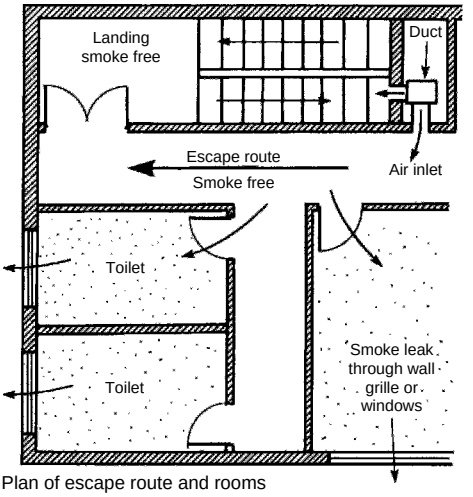


Intumescent-coated honeycomb type

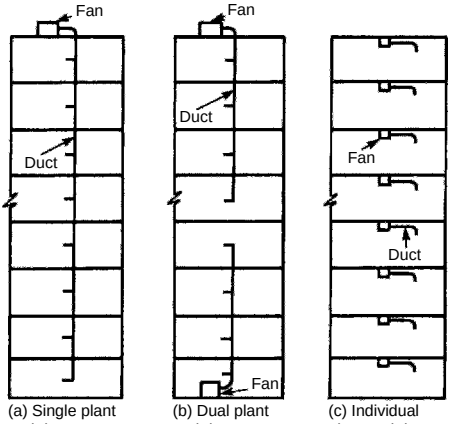
In multi-storey buildings, stairways and lobbies may be air pressurised to clear smoke and provide an unimpeded escape route. The air pressurisation is usually between 25 and 50 Pa depending on the building height and degree of exposure. This pressure is insignificant for movement of personnel. A number of pressurisation methods may be used:

- Pressurisation plant is disengaged, but it is automatically switched on by a smoke or fire detector.
- Pressurisation plant runs fully during hours of occupancy as part of the building ventilation system.
- Pressurisation plant runs continuously at a reduced capacity and output during the hours of building occupancy, but fire detection automatically brings it up to full output.

It is important to provide openings so that smoke is displaced from the escape routes to the outside air. This can be through purpose-made grilles or window vents. Pressurisation will help to limit entry of rain and draughts at external openings.



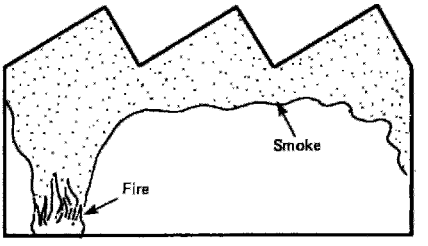
Plan of escape route and rooms



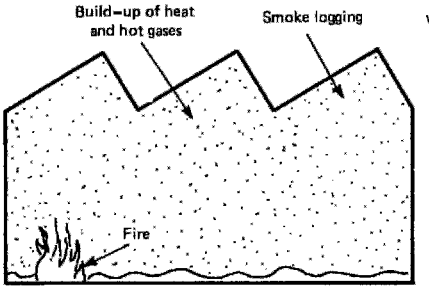
Methods of installing ductwork

Ref: BS EN 12101-6: Smoke and heat control systems. Specification for pressure differential systems. Kits.

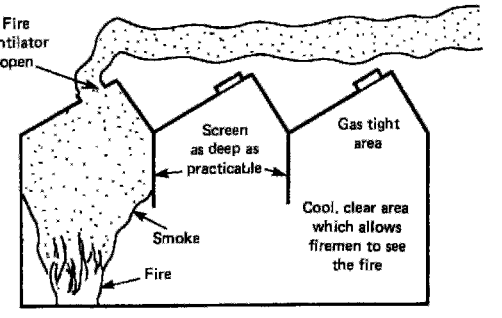
Automatic fire ventilation is designed to remove heat, smoke and toxic gases from single-storey buildings. In large factories and shopping malls, the additional volume of air entering the building by fire venting is insignificant relative to the benefits of creating clear visibility. Parts of the roof can be divided into sections by using fireproof screens which may be permanent or may fall in response to smoke detection. Fire vents are fitted at the highest part of each roof section as is practical. Heat and smoke rise within the roof section above the fire outbreak. At a pre-determined temperature, usually 70°C, a fusible link breaks and opens the ventilator above the fire. Heat and smoke escape to reduce the amount of smoke logging within the building. This will aid people in their escape and assist the fire service to see and promptly tackle the source of fire. The heat removed prevents risk of an explosion, flash-over and distortion to the structural steel frame.



Fire in unvented building showing unrestricted spread of smoke

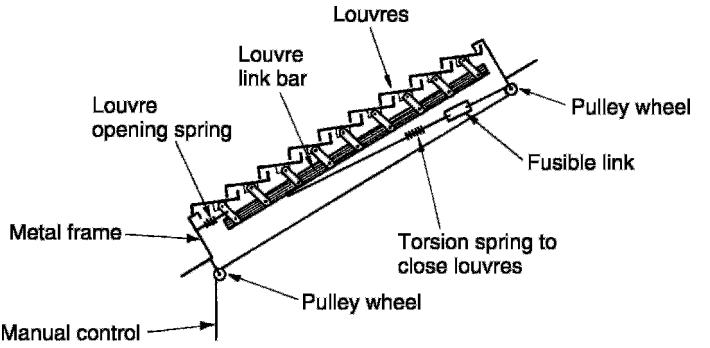


Fire in unvented building showing ultimate smoke logging



Fire in vented building showing restricted spread of smoke. The fire ventilator may also be used for normal ventilation.

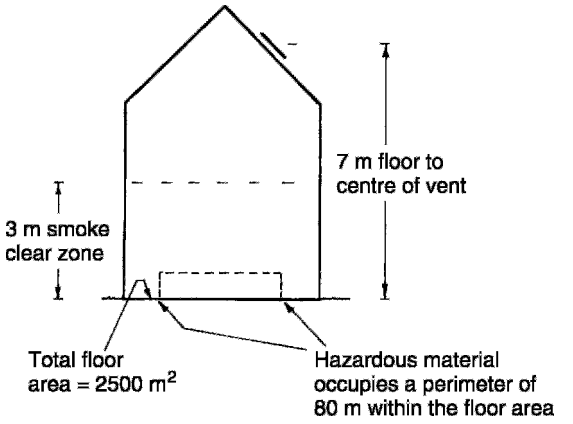
Automatic smoke and fire ventilator:



Number and area of ventilators – estimates are based on providing a smoke-free layer about 3 m above floor level.

E.g.

Floor to centre of vent height (m)	Ventilation factor (m)
4·5	0·61
7·5	0·37
10·5	0·27
13·5	0·23



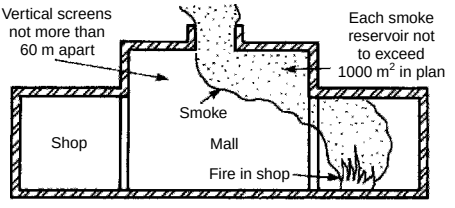
By interpolation, ventilation factor for 7 m approximates to 0·41 m.

Ventilator area can be taken as the perimeter occupied by hazardous material, multiplied by the ventilation factor, i.e. 80 m × 0·41 m. This approximates to 33 m^2 or (33/2500 × 100/1) = 1·3% of the floor area.

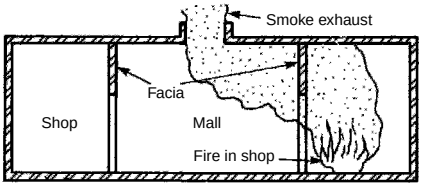
Most enclosed shopping centres have a mall with a parade of shops. The mall is the general circulation area and the obvious escape route from a fire. In these situations, a fire can generate a rapid spread of smoke and hot gases. It is therefore essential that some form of smoke control is adopted. If the central area has a normal (68°C) sprinkler system, the water may cool the smoke and hot gases to reduce their buoyancy and create an unwanted fogging effect at floor level. Therefore, consideration should be given to reducing the number of sprinkler heads and specifying a higher operating temperature. Smoke can be controlled by:

- Providing smoke reservoirs into which the smoke is retained before being extracted by mechanical or natural means.

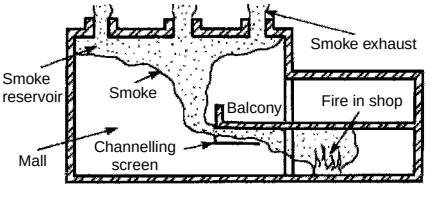
- Allowing replacement cool air to enter the central area through low level vents to displace the smoke flowing out at higher level.



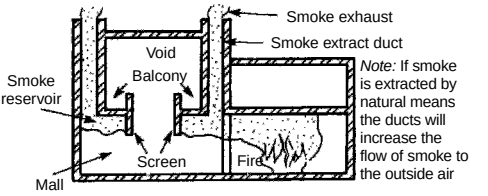
Smoke reservoir by adopting a greater ceiling height in the mall than in the shops



Smoke reservoir formed by facias above open fronted shops



Two-storey mall showing behaviour of smoke through channelling screens



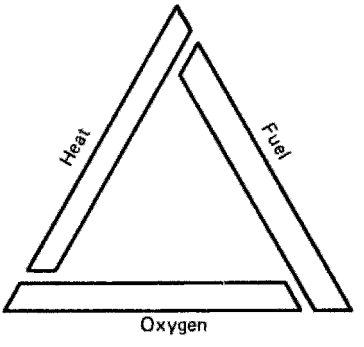
Use of smoke extract ducts through roof of mall

A portable fire extinguisher must contain the type of fire extinguishing agent suitable for the fire it is required to extinguish. It must also be clearly identifiable by colour coding for its intended purpose.

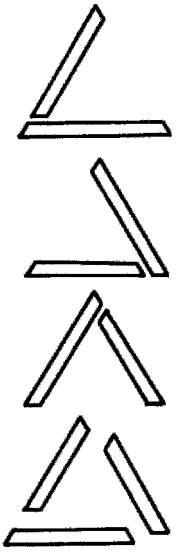
Fires can be grouped:

- Solid fuels, e.g. wood, paper, cloth, etc.
- Flammable liquids, e.g. petrol, oil, paints, fats, etc.
- Flammable gases, e.g. methane, propane, acetylene, etc.
- Flammable metals, e.g. zinc, aluminium, uranium, etc.
- Electrical.

Extinguishing agent	Extinguisher colour	Application
Water	Red	Carbonaceous fires, paper, wood, etc.
Foam	Red with cream band	Ditto and flammable liquids, oils, fats, etc.
Carbon dioxide	Red with black band	Electrical fires and flammable liquids.
Dry chemicals	Red with blue band	All fires.



Three elements required for a fire. The removal of one element will extinguish the fire



Removal of fuel (Close a fuel line valve)

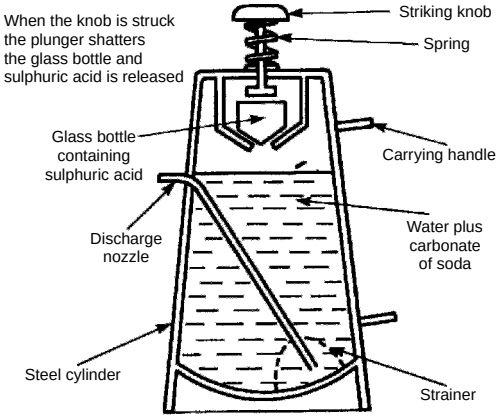
Removal of heat (Cooling)

Removal of oxygen (Smothering)

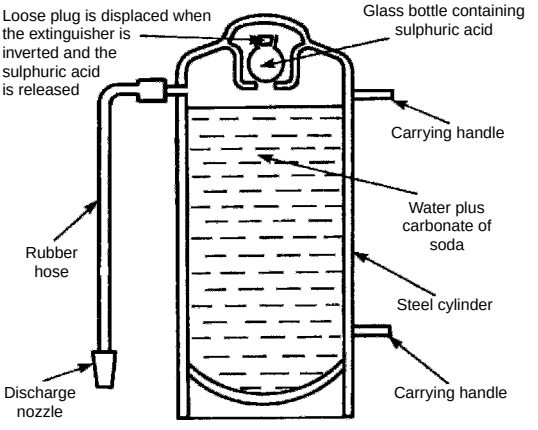
Inhibit combustion reaction

Ref: BS EN 3: Portable fire extinguishers.

Sand and water buckets are no longer acceptable as a first-aid fire treatment facility. Purpose provided extinguishers are now commonplace in public and commercial buildings. Under the obligations of the Health and Safety at Work, etc. Act, employees are required to undertake a briefing on the use and selection of fire extinguishers. Water in pressurised cylinders may be used for carbonaceous fires and these are commonly deployed in offices, schools, hotels, etc. The portable soda-acid extinguisher has a small glass container of sulphuric acid. This is released into the water cylinder when a knob is struck. The acid mixes with the water which contains carbonate of soda to create a chemical reaction producing carbon dioxide gas. The gas pressurises the cylinder to displace water from the nozzle. The inversion type of extinguisher operates on the same chemical principle.



Striking type soda–acid water portable fire extinguisher

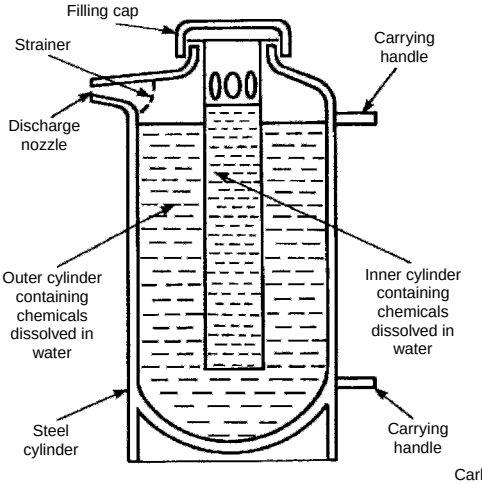


Inversion type soda–acid water portable fire extinguisher

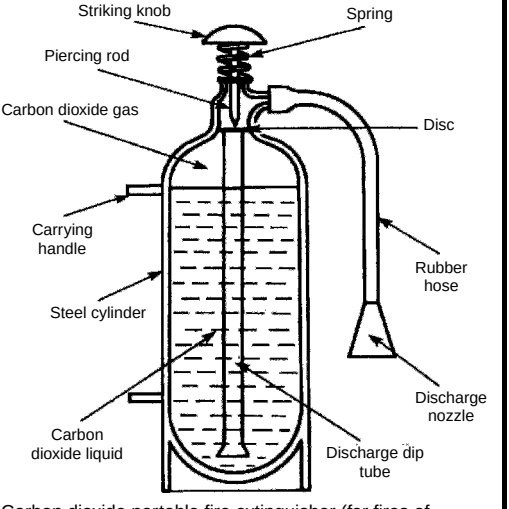
Although water is a very good cooling agent, it is inappropriate for some types of fire. It is immiscible with oils and is a conductor of electricity. Therefore, the alternative approach of breaking the triangle of fire by depleting the oxygen supply can be achieved by smothering a fire with foam. Foam is suitable for gas or liquid fires.

Chemical foam type of extinguisher – foam is formed by chemical reaction between sodium bicarbonate and aluminium sulphate dissolved in water in the presence of a foaming agent. When the extinguisher is inverted the chemicals are mixed to create foam under pressure which is forced out of the nozzle.

Carbon dioxide extinguisher – carbon dioxide is pressurised as a liquid inside a cylinder. Striking a knob at the top of the cylinder pierces a disc to release the carbon dioxide which converts to a gas as it depressurises through the extinguisher nozzle.

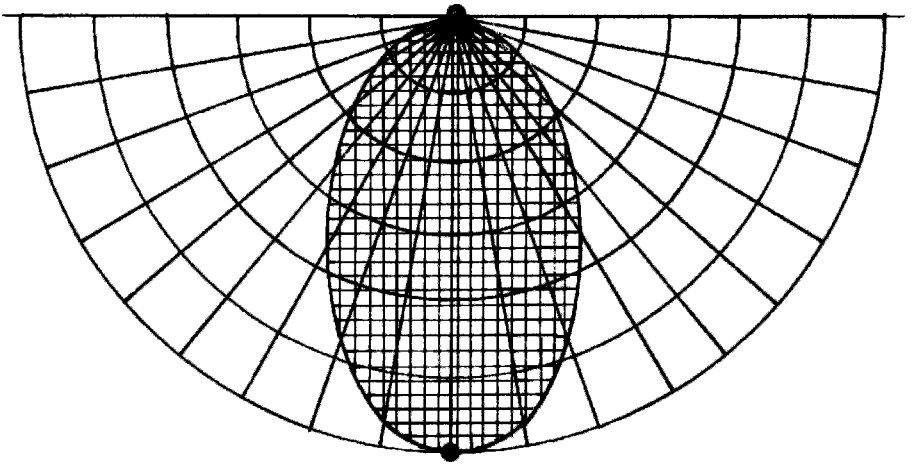


Chemical foam portable fire extinguisher (inversion type)



Carbon dioxide portable fire extinguisher (for fires of liquids and gases and electrical fires)

13 SECURITY INSTALLATIONS



INTRUDER ALARMS
MICRO-SWITCH AND MAGNETIC REED
RADIO SENSOR, PRESSURE MAT AND TAUT WIRING
ACOUSTIC, VIBRATION AND INERTIA DETECTORS
ULTRASONIC AND MICROWAVE DETECTORS
ACTIVE INFRA-RED DETECTOR
PASSIVE INFRA-RED DETECTOR
LIGHTNING PROTECTION SYSTEMS

Intruder alarms have developed from a very limited specialist element of electrical installation work in high security buildings to the much wider market of schools, shops, offices, housing, etc. This is largely a result of the economics of sophisticated technology surpassing the efficiency of manual security. It is also a response to the increase in burglaries at a domestic level. Alarm components are an alarm bell or siren activated through a programmer from switches or activators. Power is from mains electricity with a battery back-up. Extended links can also be established with the local police, a security company and the facility manager's central control by telecommunication connection.

Selection of switches to effect the alarm will depend on the building purpose, the extent of security specified, the building location and the construction features. Popular applications include:

- Micro-switch
- Magnetic reed
- Radio sensor
- Pressure mat
- Taut wiring
- Window strip
- Acoustic detector
- Vibration, impact or inertia detector

The alternative, which may also be integrated with switch systems, is space protection. This category of detectors includes:

- Ultrasonic
- Microwave
- Active infra-red
- Passive infra-red

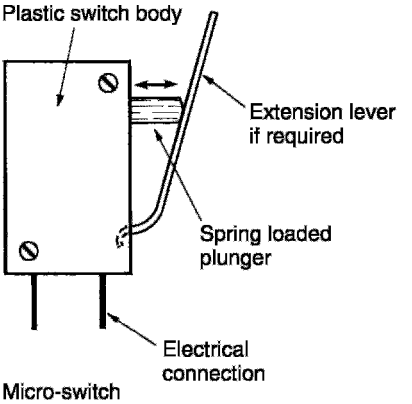
Circuit wiring may be `open' or `closed' as shown in principle for fire alarms – see pages 490 and 491. The disadvantage of an open circuit is that if an intruder knows the whereabouts of cables, the detector circuit can be cut to render the system inoperative. Cutting a closed circuit will effect the alarm.

The following reference provides detailed specifications:

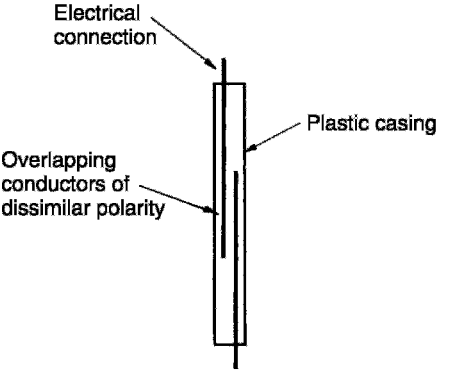
BS EN 50131-1: Alarm systems. Intrusion systems. General requirements.

Micro-switch – a small component which is easily located in door or window openings. It is the same concept and application as the automatic light switch used in a vehicle door recess, but it activates an alarm siren. A spring loaded plunger functions in a similar manner to a bell push button in making or breaking an electrical alarm detector circuit. The disadvantage is the constant movement and associated wear, exposure to damage and possible interference.

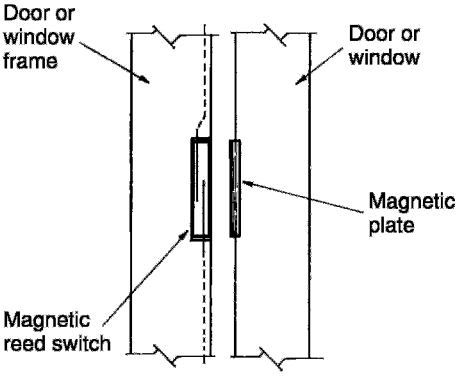
Magnetic reed – can be used in the same situations as a micro-switch but it has the advantage of no moving parts. It is also less exposed to damage or tampering. There are, however, two parts to install. One is a plastic case with two overlapping metal strips of dissimilar polarity, fitted into a small recess in the door or window frame. The other is a magnetic plate attached opposingly to the door or window. When the magnet is close to the overlapping strips, a magnetic field creates electrical continuity between them to maintain circuit integrity. Opening the door or window demagnetises the metal strips, breaking the continuity of the closed detector circuit.



Micro-switch



Magnetic reed switch

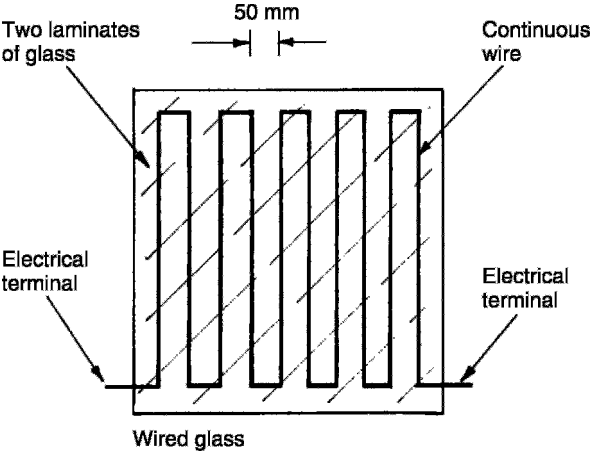


Switch location

Radio sensor – these are surface mounted to windows and doors. They transmit a radio signal from an integral battery power source. This signal is picked up by a central control unit or receiver, which activates the alarm circuit. As these sensors are 'free wired' they can be moved, which is ideal for temporary premises or in buildings undergoing changes. A pocket or portable radio panic button transmitter is an option. The range without an aerial is about 60 m, therefore they can be used in outbuildings to a hard wired system from a main building.

Pressure mat – these are a 'sandwich' with metal foil outer layers as part of a detector circuit. The inner core is a soft perforated foam. Pressure on the outer upper layer connects to the lower layer through the perforations in the core to complete the circuit and activate the alarm. Location is near entrances and under windows, normally below a carpet where a small area of underlay can be removed. Sensitivity varies for different applications, such as premises where household pets occupy the building.

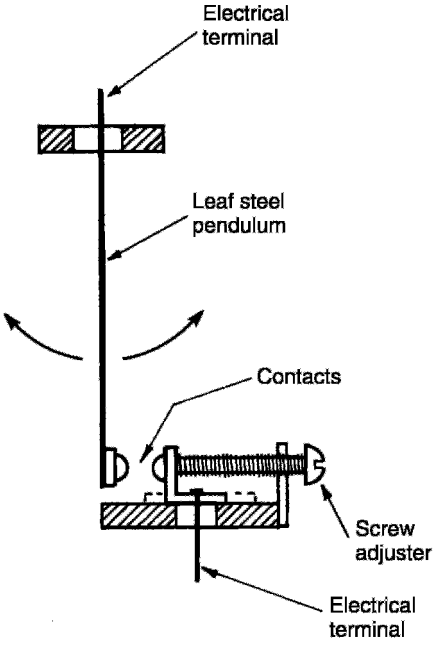
Taut wiring – also available as a window strip. A continuous plastic coated copper wire is embedded in floors, walls or ceilings, or possibly applied around safes and other secure compartments. As a window strip, silvered wire can be embedded between two bonded laminates of glass. Alternatively, a continuous self-adhesive lead or aluminium tape can be applied directly to the surface. In principle, it is similar to a car rear heated window. When the wire or tape is broken the closed circuit is interrupted which activates the alarm circuit.



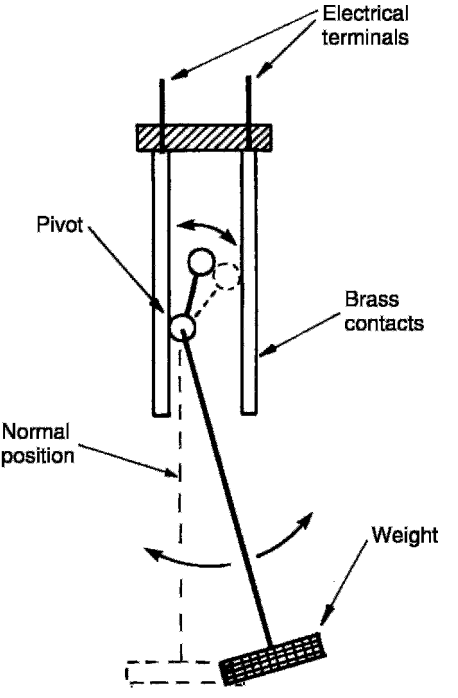
Acoustic – also known as sonic detectors. They are used mainly for protection against intruders in commercial and industrial premises. A sound receiver comprises a microphone, amplifier and an output relay. Also included is a filter circuit which can be tuned to respond to specific sound frequencies such as that produced by breaking glass.

Vibration – a slender leaf of steel is suspended between two electrical contacts. Hammering or structural impact produces vibration in the pendulum, sufficient for the contacts to meet and complete a detector circuit. Adjustment allows for a variety of applications, e.g. where a road or railway is adjacent and intermittent vibration would occur.

Inertia – these respond to more sensitive movements than vibrations, so would be unsuitable near roads, railways, etc. They are ideal to detect the levering or bending of structural components such as window sashes and bars. A pivotal device is part of a closed circuit, where displacement of its weight breaks the circuit continuity.



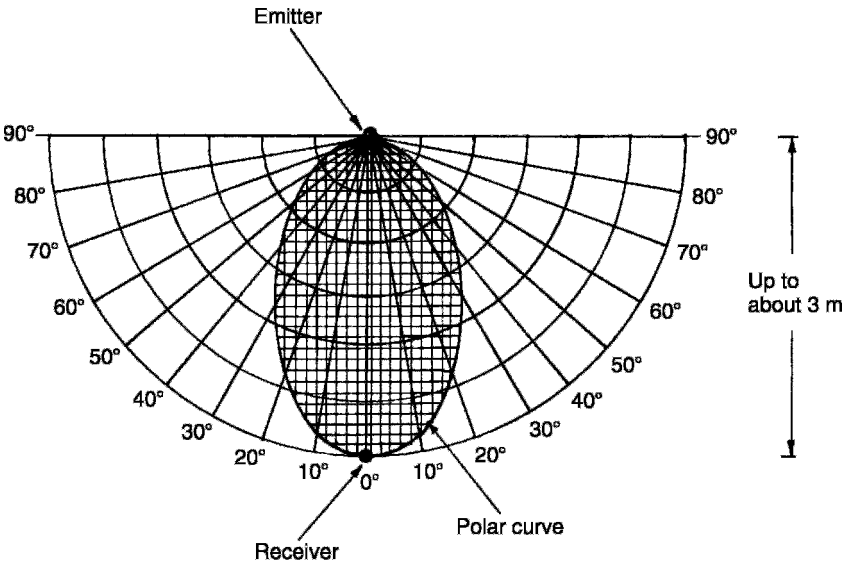
Vibration detector



Inertia detector

Ultrasonic – the equipment is simply a sound emitter and a receiver containing a microphone and sound processor. The sounds are at a very high frequency of between 20 and 40 kHz (normal hearing limit is about 15 kHz). Direct and indirect (reflected) sound distribution from the emitter to the receiver adopts a pattern which can be plotted as a polar curve. If an intruder encroaches the curve the sound frequency will be disturbed. The receiver then absorbs the original frequency, the frequency reflected off the intruder and a mixture of the two. The latter is known as the 'beat note' and it is this irregularity which effects the detector circuit. Greatest detection potential is in the depth of the lobe, therefore this should be projected towards an entry point or a window.

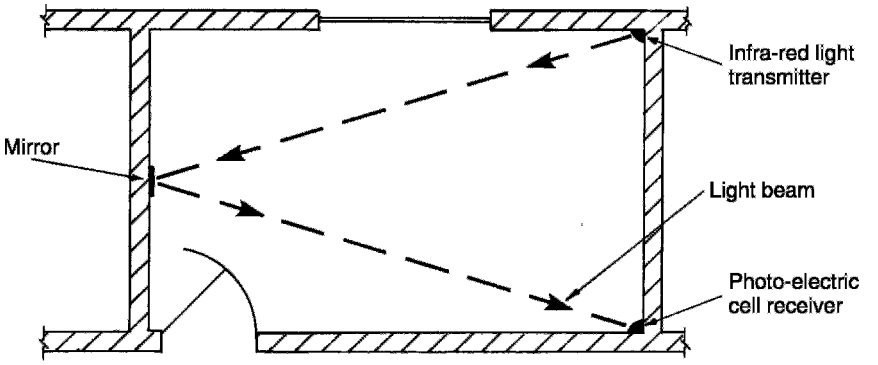
Microwave – operates on the same principle as ultrasonic detection, except that extremely high radio waves are emitted at a standard 10·7 GHz. Emitter and receiver occupy the same unit which is mounted at high level to extend waves over the volume of a room, warehouse, office or similar internal area. An intruder penetrating the microwaves disturbs the frequency which effects the detector circuit. Unlike ultrasonic detectors, microwave detectors are not disturbed by air currents, draughts and ultrasonic sounds from electrical equipment such as computers. They are therefore less prone to false alarms.



Typical ultrasonic detector response zone

Otherwise known as an optical system, it uses a light beam from the infra-red part of the electromagnetic spectrum. This is imperceptible to the human eye. The system is based on a transmitter and receiver. The transmitter projects an invisible light beam at distances up to 300 m on to a photo-electric cell receiver. An intruder crossing the beam will prevent the light from activating the cell. The loss of energy source for the cell effects an alarm relay. Even though the beam has extensive range, this system is not suitable for external use.

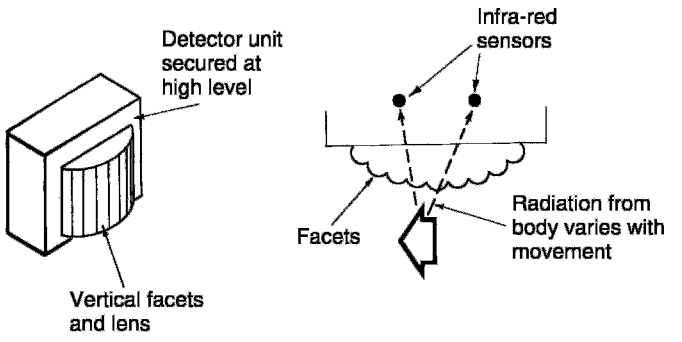
Atmospheric changes such as fog or birds flying through the beam can affect the transmission. Mirrors may be used to reflect the beam across a room or around corners, but each reflection will reduce the beam effectiveness by about 25%. Infra-red beams will penetrate glass partitions and windows, each pane of glass reducing the beam effectiveness by about 16%. The smarter intruder may be able to fool the system by shining a portable light source at the receiver. This can be overcome by pulsing the transmission, usually at about 200 pulses per second.



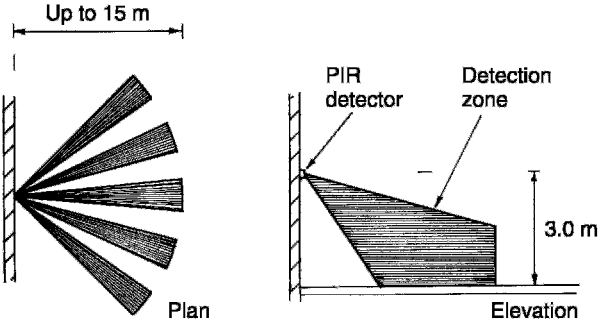
Infra-red light beam application

Passive Infra-red (PIR) Detector

These detectors use highly sensitive ceramic infra-red receivers to recognise radiation from a moving body. Wall-mounted detector units focus the radiation through a lens which contains curved facets to concentrate the radiation on to two sensors. Image variation between the sensors generates a small electrical differential to effect an alarm relay. These systems have enjoyed widespread application, not least the domestic market. Units of lower sensitivity can be used where pets occupy a home. A battery back-up energy source covers for periods of mains power isolation. PIR detectors can be used with other devices in the same system, e.g. radio pocket panic buttons, pressure mats, magnetic reeds, etc. PIR beam patterns vary in form and range to suit a variety of applications, both externally and internally.

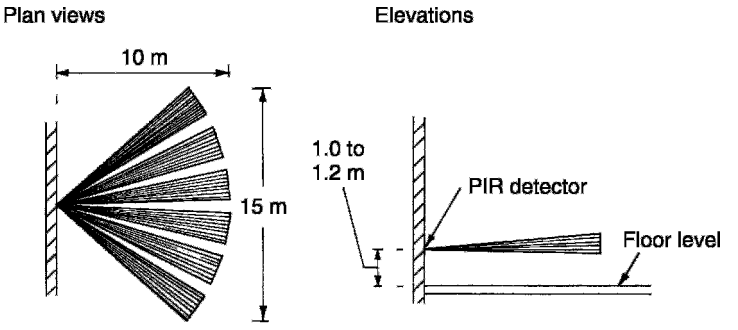


PIR detector unit, typically 75 × 50 mm

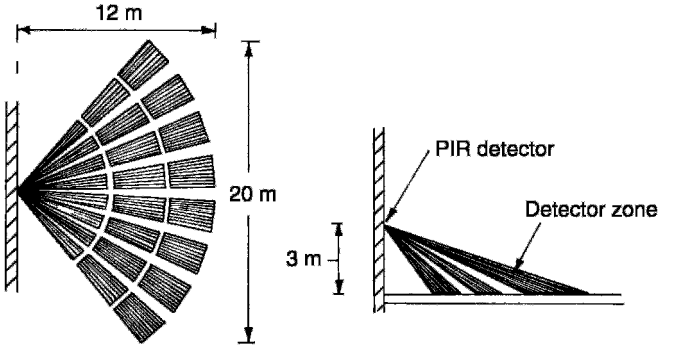


Typical pattern displacement for wall-mounted detector

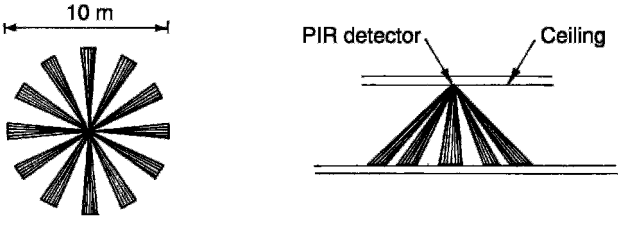
Typical patterns:



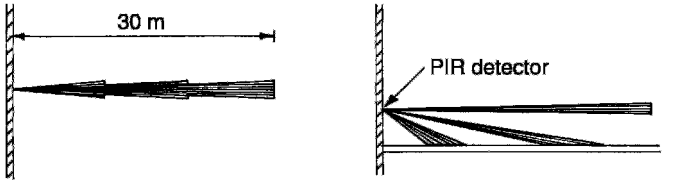
Domestic small animals



Large area – split vertical zones



Circular coverage from overhead detector



Narrow coverage for stairways and corridors

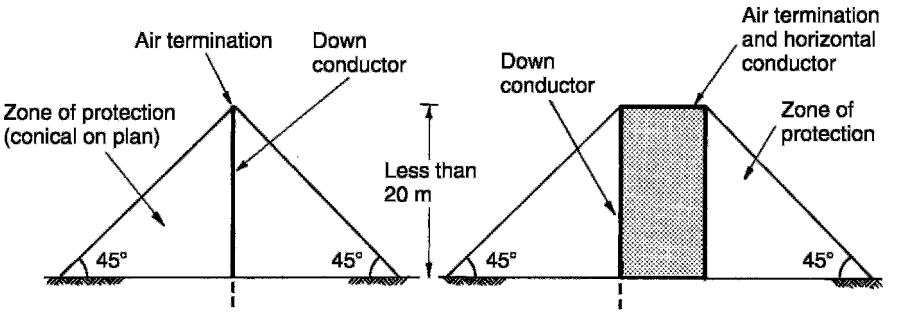
Lightning occurs as a result of electrostatic discharge between clouds or between a cloud and the ground. The potential is up to 100 MV with the current peaking at about 200 kA. The average current is about 20 kA. The number of days that thunderstorms occur in the UK varies between 5 and 20 per year, depending on location. Consequently, some degree of protection to buildings and their occupants is necessary.

As the risk of lightning striking a particular building is low, not all buildings are protected. Houses have least priority and are rarely protected, but other purpose groups will be assessed by their owners and their insurers. This will be on the basis of height, contents, function, type of construction (extent of metalwork, e.g. lead roofing), likelihood of thunderstorms in locality, extent of isolation and the general topography. Even where a lightning protection system is provided it is unlikely to prevent some lightning damage to the building and its contents.

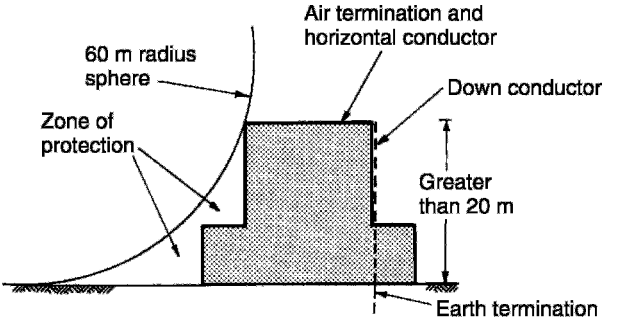
Function of a lightning protection system – to attract a lightning discharge which might otherwise damage exposed and vulnerable parts of a building. To provide a path of low impedance to an earth safety terminal.

Zone of protection – the volume or space around a conductor which is protected against a lightning strike. It can be measured at 45° to the horizontal, descending from the apex of the conductor. For buildings less than 20 m in height the zone around a vertical conductor is conical. For buildings exceeding 20 m, the zone can be determined graphically by applying a 60 m radius sphere to the side of a building. The volume contained between the sphere and building indicates the zone. See next page for illustrations.

Zones of protection:



Protection zones for buildings <20 m height



Protection zones for buildings >20 m height

Air terminations – these are provided to intercept a lightning strike. No part of a roof should exceed 5 m from part of a termination conductor, unless it is a lower level projection which falls within the zone of protection. Metallic components such as aerials, spires, cooling towers, etc., should be connected to a terminal. Apart from specific apexes such as spires, air terminations are horizontal conductors running along the ridge of a pitched roof or around the periphery of a flat roof. If the roof is of sufficient size, a 20 m × 10 m grid or lattice of parallel terminations should be provided.

Down conductors – these provide a low impedance route from the air terminations to the earth terminal. They should be direct, i.e. vertical without bends and re-entrant loops. Spacing for buildings up to 20 m in height is 1 per 20 m of periphery starting at the corners and at equal distance apart. Building in excess of 20 m height require 1 per 10 m, at corners and equi-spaced. All structural steelwork and metal pipes should be bonded to the down conductor to participate in the lightning discharge to earth.

Fixing centres for all conductors:

Horizontal and vertical – 1 m max.
Horizontal and vertical over 20 m long – 750 mm max.
25 m long – 500 mm max.

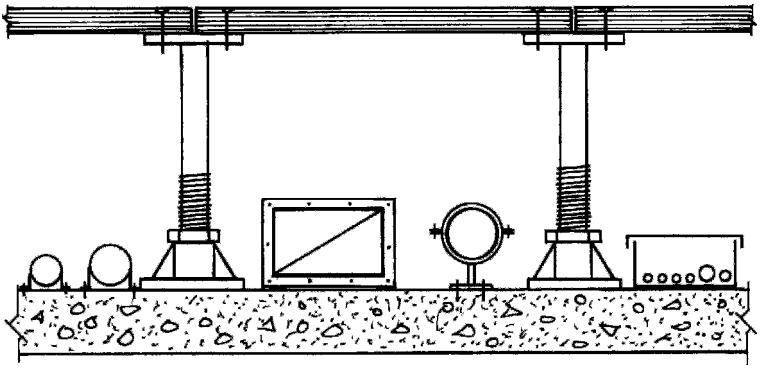
Minimum dimensions of conductors: 20 mm × 4 mm (80 mm^2) or
10 mm diameter (80 mm^2).

Conductor materials – aluminium, copper and alloys, phosphor-bronze, galvanised steel or stainless steel.

Earth termination – this is required to give the lightning discharge current a low resistance path to earth. The maximum test resistance is 10 ohms for a single terminal and where several terminals are used, the combined resistance should not exceed 10 ohms. Depth of terminal in the ground will depend on subsoil type. Vertical earthing rods of 10 or 12 mm diameter hard drawn copper are preferred, but stronger phosphor-bronze or even copper-coated steel can be used if the ground is difficult to penetrate. Alternatively, a continuous horizontal strip electrode may be placed around the building at a depth of about one metre. Another possibility is to use the reinforcement in the building's foundation. To succeed there must be continuity between the structural metalwork and the steel reinforcement in the concrete piled foundation.

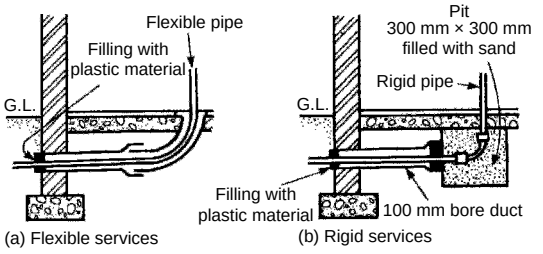
Ref: BS 6651: Code of practice for protection of structures against lightning.

14 ACCOMMODATION FOR BUILDING SERVICES



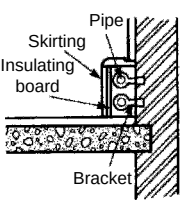
DUCTS FOR ENGINEERING SERVICES
FLOOR AND SKIRTING DUCTS
MEDIUM AND LARGE VERTICAL DUCTS
MEDIUM AND LARGE HORIZONTAL DUCTS
SUBWAYS OR WALKWAYS
PENETRATION OF FIRE STRUCTURE BY PIPES
RAISED ACCESS FLOORS
SUSPENDED AND FALSE CEILINGS

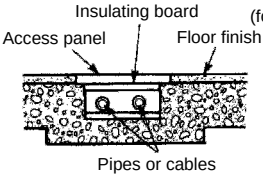
Before installing ducts for the entry of services into a building, it is essential to ascertain the location of pipes and cables provided by the public utilities companies. Thereafter, the shortest, most practicable and most economic route can be planned. For flexible pipes and cables, a purpose-made plastic pipe duct and bend may be used. For rigid pipes or large cables, a straight pipe duct to a pit will be required. Pipe ducts must be sealed at the ends with a plastic filling and mastic sealant, otherwise subsoil and other materials will encroach into the duct. If this occurs, it will reduce the effectiveness of the void around the pipe or cable to absorb differential settlement between the building and incoming service. To accommodate horizontal services, a skirting or floor duct may be used. These may be purpose made by the site joiner or be standard manufactured items. Vertical services may be housed in either a surface-type duct or a chase. The latter may only be used if the depth of chase does not affect the structural strength of the wall. The reduction in the wall's thermal and sound insulation properties may also be a consideration. No water installation or fitting should be embedded in a wall or floor.



(a) Flexible services (b) Rigid services

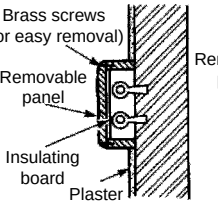
Ducts for entry of services into the building

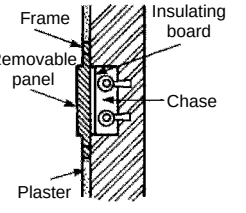




(a) Skirting type (b) Floor duct

Horizontal ducts for small pipes or cables





(a) Surface type (b) Recessed type

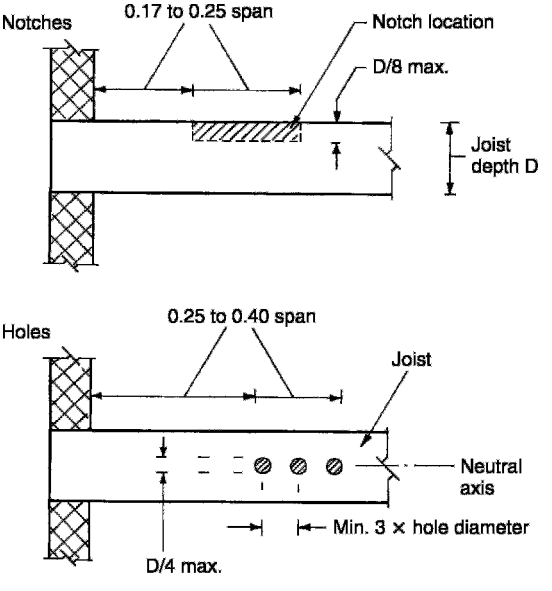
Vertical ducts for small pipes or cables

Ref. The Water Supply (Water Fittings) Regulations.

Services installations may be concealed within the structure by an access board or panel. The structure and its components should not be damaged to accommodate services but some nominal holing and notching will be unavoidable and is acceptable. Wherever possible, pipes and cables should run parallel and be secured to the side of joists. Where services are at right angles to joists the optimum location is through a hole in the joist centre or neutral axis. This is where compressive and tensile stresses are minimal. Holing is convenient for cables and flexible pipes, but notching the top of joists is the only practical means for accommodating rigid pipes. Notching will reduce the strength of joists, therefore where services are apparent, the structural designer should be informed and the joists oversized accordingly.

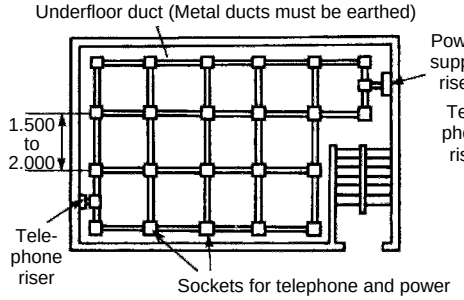
Restrictions and guidance – the principal areas to avoid notching and holing of joists are mid-span (maximum bending) and close to supports (maximum shear).

- Notches not greater than 0·125 × joist depth.
- Notches located between 0·17 and 0·25 times the span, from support.
- Hole diameter, maximum of 0·25 × joist depth.
- Holes a minimum of 3 × diameter apart.
- Holes located between 0·25 and 0·40 times the span, from support.

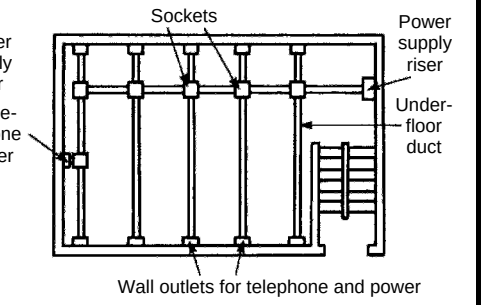


Recommended location of notches and holes in joists

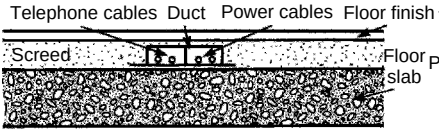
A grid distribution of floor ducting is appropriate in open plan offices and shops where there is an absence of internal walls for power and telecommunications sockets. It is also useful in offices designed with demountable partitioning where room layout is subject to changes. Sockets are surface mounted in the floor with a hinged cover plate to protect them when not in use. The disruption to the structure is minimal as the ducts can be set in the screed, eliminating the need for long lengths of trailing cables to remote workstations. For partitioned rooms, a branching duct layout may be preferred. The branches can terminate at sockets near to the wall or extend into wall sockets. Where power supplies run parallel with telecommunications cables in shared ducts, the services must be segregated and clearly defined. For some buildings, proprietary metal, plastic or laminated plywood skirting ducts may be used. These usually have socket outlets at fixed intervals.



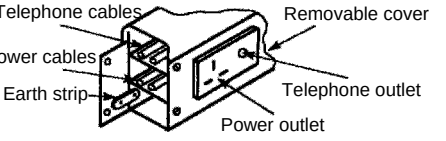
Grid layout floor duct



Branching layout floor duct

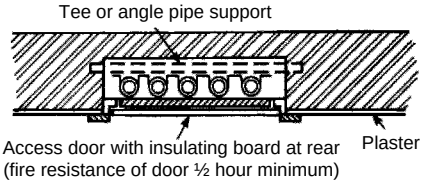


Section through floor duct

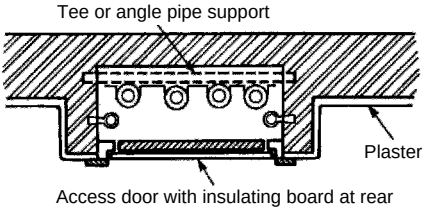


Metal skirting duct

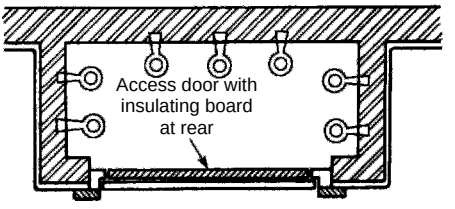
The purpose of a service duct is to conceal the services without restricting access for inspection, repair and alterations. A duct also helps to reduce noise and protect the services from damage. When designing a service duct, the transmission of noise, possible build-up of heat in the enclosure and accessibility to the services must be considered. The number of ducts required will depend on the variation in services, the need for segregation and location of equipment served. Vertical ducts usually extend the full height of a building which is an important factor when considering the potential for spread of fire. The duct must be constructed as a protected shaft and form a complete barrier to fire between the different compartments it passes. This will require construction of at least 60 minutes' fire resistance with access doors at least half the structural fire resistance.



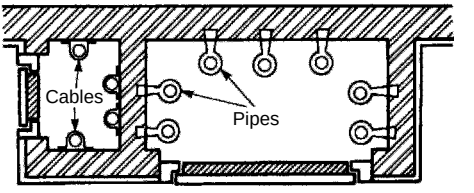
Recessed for medium-sized pipes and cables



Partially recessed for medium-sized pipes and cables



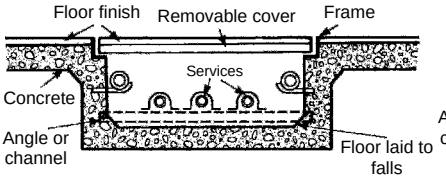
Built-out for large pipes



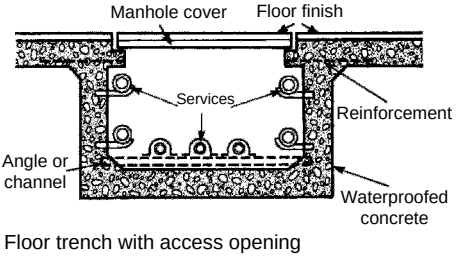
Built-out for large pipes and cables

Refs.: BS 8313: Code of practice for accommodation of building services in ducts.
Building Regulations, Approved Document B3: Internal fire spread (structure).

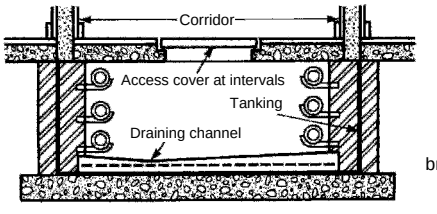
Floor trenches are usually fitted with continuous covers. Crawl-ways generally have access covers of minimum 600 mm dimension, provided at convenient intervals. A crawl-way should be wide enough to allow a clear working space of at least 700 mm and have a minimum headroom of at least 1 m. Continuous trench covers may be of timber, stone, reinforced concrete, metal or a metal tray filled to match the floor finish. The covers should be light enough to be raised by one person, or, at most, two. Sockets for lifting handles should be incorporated in the covers. In external situations, the cover slabs (usually of stone or concrete) can be bedded and joined together with a weak cement mortar. If timber or similar covers are used to match a floor finish, they should be fixed with brass cups and countersunk brass screws. A trench has an internal depth of less than 1 m. In internal situations where ducts cross the line of fire compartment walls, a fire barrier must be provided within the void and the services suitably fire stopped (see pages 325 and 520).



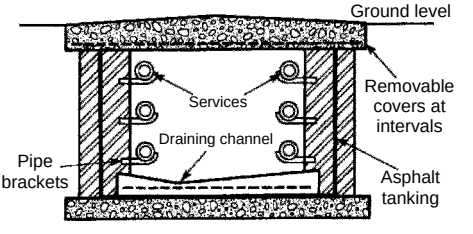
Floor trench with removable cover



Floor trench with access opening

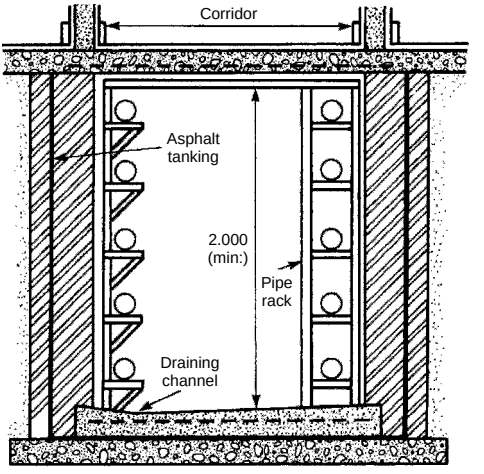


Crawl-way inside a building

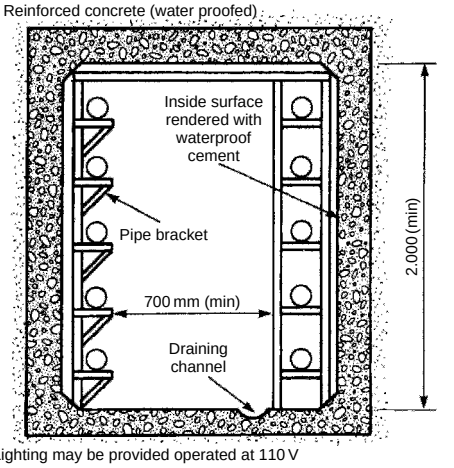


Crawl-way in open ground

Access to a subway will normally be from a plant room, control room or a basement. Additional access from the surface should also be provided at convenient junctions and direction changes. See page 233 for provision of wall step irons. The design and construction of these ducts should adequately withstand the imposed loads and pressures that will occur under extreme working conditions. They should be watertight and where used internally have adequate resistance to fire. Ducts housing boiler or control room services must be provided with a self closing fire door at the entry. Ventilation to atmosphere is essential and a shallow drainage channel should convey ground water leakage and pipe drainage residue to a pumped sump or a gully connection to a drain.



Subway inside a building



Note Lighting may be provided operated at 110 V

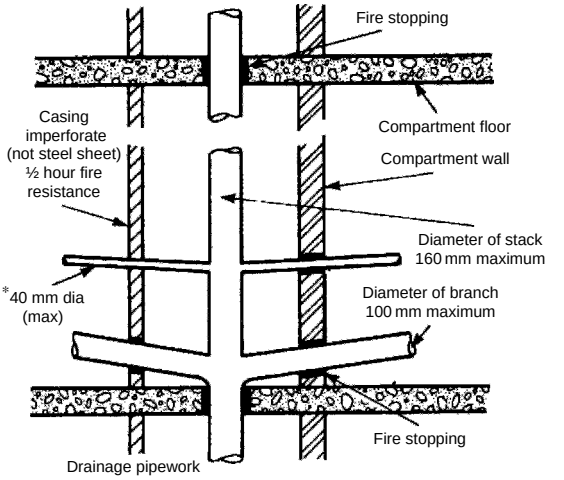
Subway in open ground

The effect of fire spreading through the voids associated with internal pipework penetrating fire resistant walls and floors can be considered in four areas:

1. Addition of fuel to the total fire load.
2. Production of toxic gases and smoke.
3. Risk of fire spread along the pipework.
4. Reduction in fire resistance of the building elements penetrated.

Guidance in Approved Document B3 to the Building Regulations is mostly applied to sanitation pipework penetrating the structure, but could affect other services, particularly in large buildings. Acceptable sleeving and sealing methods for uPVC discharge pipes are shown on page 325. Non-combustible pipe materials up to 160 mm nominal i.d. (excluding lead, aluminium, aluminium alloys, uPVC and fibre cement) may have the structural opening around the pipe fire stopped with cement mortar, gypsum plaster or other acceptable non-combustible material. Where the pipe material is one of those listed in parentheses, and it penetrates a wall separating dwellings or a compartment wall or floor between flats, the discharge stack is limited to 160 mm nominal i.d. and branch pipes limited to 110 mm nominal i.d., provided the system they are part of is enclosed as shown.

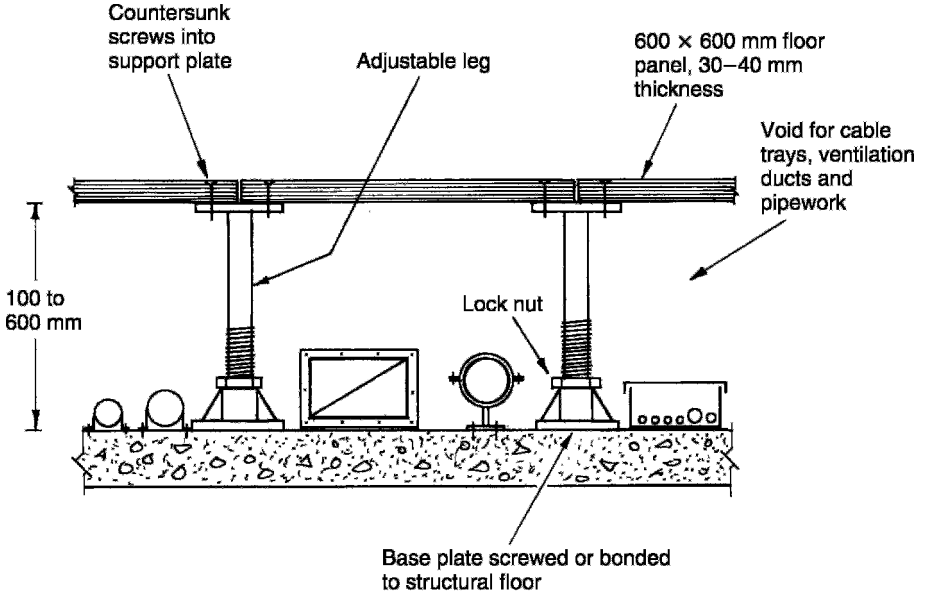
* Any other materials, e.g. polypropylene, have a maximum nominal i.d. of 40 mm.



Pipes inside a protected shaft

Ref: Building Regulations, Approved Document B3: Internal fire spread (structure).

Raised flooring provides discrete housing for the huge volumes of data and telecommunications cabling, electrical power cables, pipes, ventilation ducts and other services associated with modern buildings. Proprietary raised floors use standard 600 mm square interchangeable decking panels, suspended from each corner on adjustable pedestals. These are produced in a variety of heights to suit individual applications, but most range between 100 mm and 600 mm. Panels are generally produced from wood particle board and have a galvanised steel casing or overwrap to enhance strength and provide fire resistance. Applied finishes vary to suit application, e.g. carpet, wood veneer, vinyl, etc. Pedestals are screw-threaded steel or polypropylene legs, connected to a panel support plate and a base plate. The void between structural floor and raised panels will require fire stopping at specific intervals to retain the integrity of compartmentation.

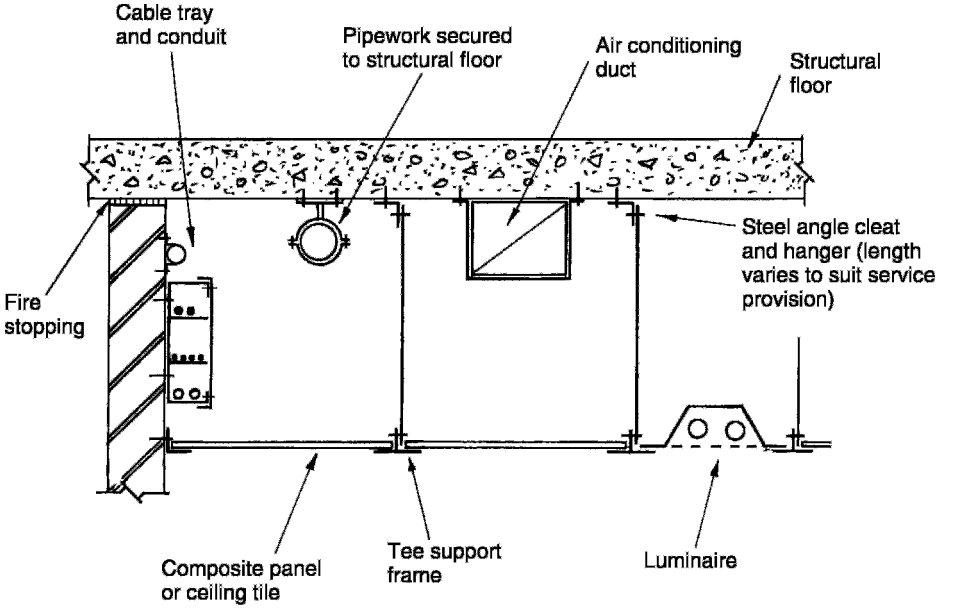


Raised access floor

Ref: BS EN 12825: Raised access floors.

A suspended ceiling contributes to the fire resistance of a structural floor. The extent of contribution can be determined by reference to Appendix A in Approved Document B of the Building Regulations. An additional purpose for a suspended ceiling is to accommodate and conceal building services, which is primarily the function of a false ceiling.

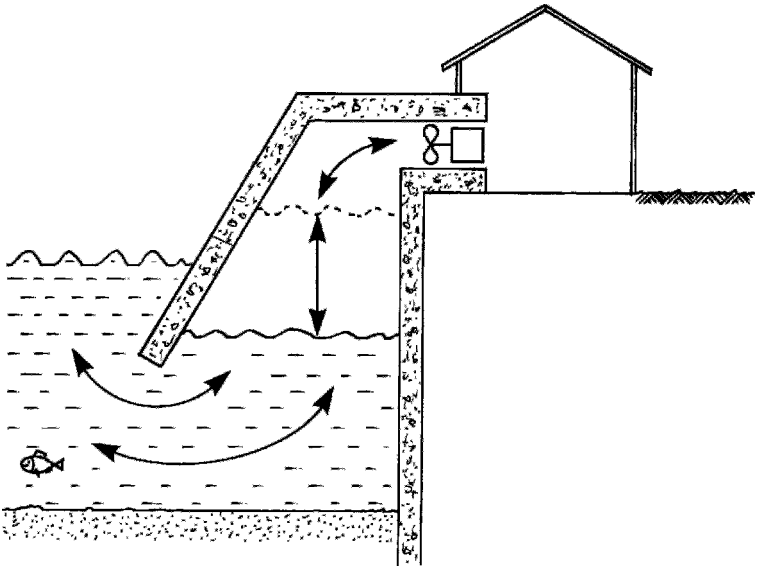
False ceiling systems may be constructed in situ from timber or metal framing. A grid or lattice support system is produced to accommodate loose fit ceiling tiles of plasterboard, particle board or composites. Proprietary systems have also become established. These are a specialised product, usually provided by the manufacturer on a design and installation basis. Most comprise a simple metal framing with interconnecting panel trays. As with raised flooring, the possibility of fire spreading through the void must be prevented. Fire stopping is necessary at appropriate intervals as determined in Approved Document B3 to the Building Regulations.



Simply suspended ceiling

Ref: BS EN 13964: Suspended ceilings. Requirements and test methods.
Building Regulations, Approved Document B: Fire safety.

15 ALTERNATIVE AND RENEWABLE ENERGY



ALTERNATIVE ENERGY
WIND POWER
FUEL CELLS
WATER POWER
GEOTHERMAL POWER
SOLAR POWER
BIOMASS OR BIOFUEL

Power stations that burn conventional fossil fuels such as coal and oil, and to a lesser extent natural gas, are major contributors to global warming, production of greenhouse gases (including CO_2) and acid rain. Note: Acid rain occurs when the gaseous products of combustion from power stations and large industrial plant combine with rainfall to produce airborne acids. These can travel hundreds of miles before having a devastating effect on forests, lakes and other natural environments. Current efforts to limit the amount of combustion gases in the atmosphere include:

- CHP and district heating systems (pages 102–105).
- Condensing boilers (page 51).
- Higher standards of thermal insulation of buildings (page 123 and Building Regulations, Approved Document L – Conservation of fuel and power).
- Energy management systems (pages 119 and 121).
- Recycling of waste products for renewable energy.

Renewable energy is effectively free fuel, but remarkably few of these installations exist in the UK. Other European states, particularly the Netherlands, Germany and Scandinavian countries, have waste segregation plant and selective burners as standard equipment at many power stations. City domestic rubbish and farmers' soiled straw can be successfully blended with conventional fuels to power electricity generators and provide hot water for distribution in district heating mains. Small-scale waste-fired units from 60 kW up to 8000 kW are standard installations in many continental domestic and commercial premises, but are something of a rarity in this country.

Renewable and other alternative 'green' energy sources are also becoming viable. These include:

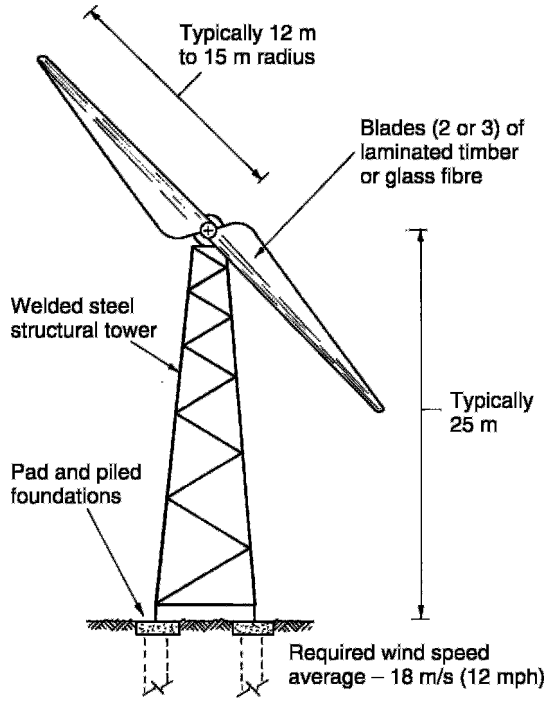
- Wind power.
- Wind power and hydrogen-powered fuel cells.
- Wave power.
- Geothermal power.
- Solar power.
- Biomass or biofuels.

The UK government have established the following objectives for power generation from 'green' sources:

2002 – 3%, 2010 – 10% and 2020 – 20%.

Atmospheric emissions of CO_2 should decline by 20% by 2010.

The development of wind power as an alternative energy source is well advanced. However, it is dependent on the fickle nature of the weather and can only be regarded as a supplementary energy source unless the surplus power produced is stored – see page 527.



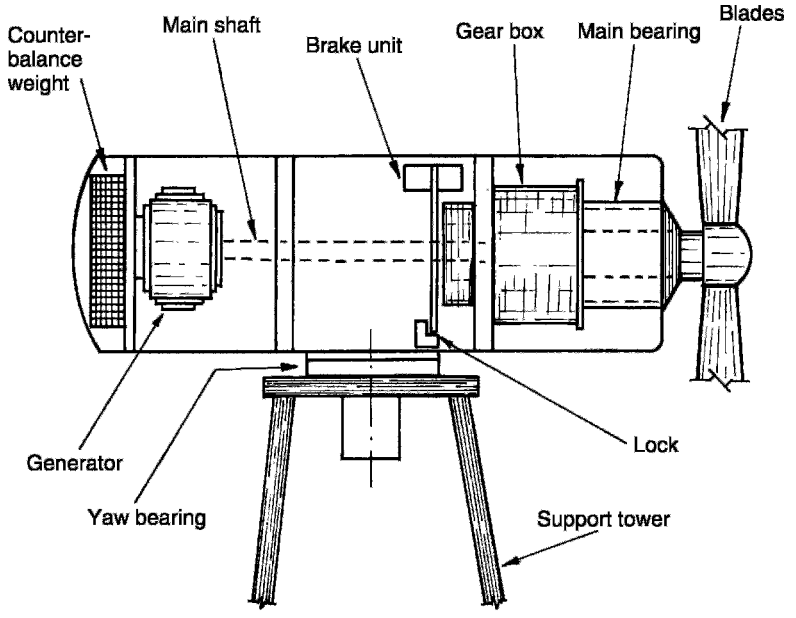
Wind power generator

The principle is simple enough. Wind drives a propeller, which rotates a shaft through a gearbox to drive an electricity generator. The generator produces direct current, similar in concept to a much smaller bicycle dynamo. Designs include two- and three-blade variants, elevated to between 25 and 45 metres from ground level to central axis. Blades are usually made from laminated timber or glass fibre and manufactured to tip diameters of between 6 and 60 metres (25 to 30 m is typical). Electricity output is difficult to define, but claims are made of 300 kW in a 25 mph wind from one generator. This is enough electricity for about 250 houses. A wind farm of say 20 generators in an exposed location could produce 20 GW of electricity an hour averaged over a year.

Environmental issues – no release of carbon, sulphur or nitrogen oxides, methane and other atmospheric pollutants. Conservation of finite fossil fuels. Aesthetically undesirable and noisy.

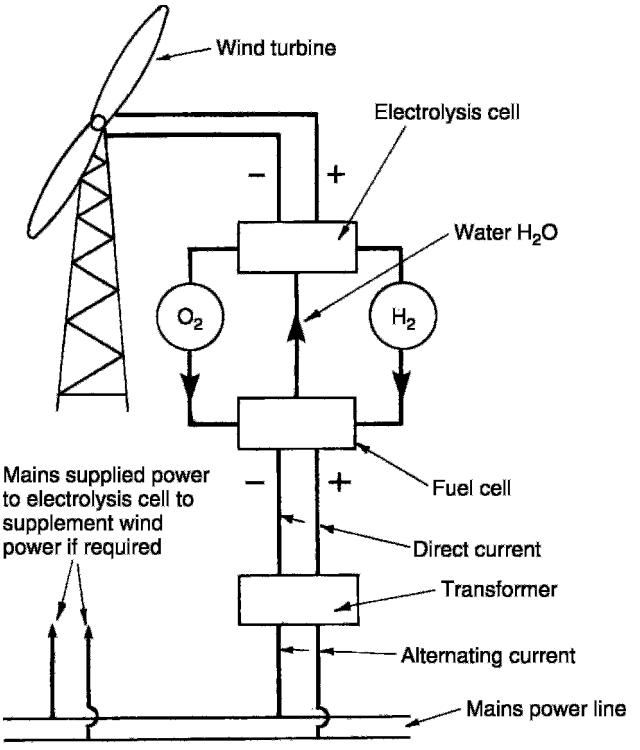
Costs – produces electricity for a minimal amount. Foundation costs are very high to anchor the units against lateral wind forces and dynamic forces during rotation. The capital cost of generators and their installation costs must be calculated against the long-term savings and environmental benefits. The purchase costs of wind turbines commence at about 1200 per kW of output, with a life expectancy of about 30 years. The smallest of units may take about a week to install.

Savings – estimates vary from speculative projections to realistic comparisons. A small generator such as that used at Wansbeck General Hospital, Northumberland, can produce up to 450 kW daily. On a greater scale, it is anticipated that by the year 2025, up to 20% of the UK's electrical energy requirements could be wind generated.



Main components of a wind turbine

Wind is limited as a source of electrical power because of the unreliable nature of the weather. To use the potential of the wind effectively, it is necessary to store the energy generated when the wind blows and release it in response to demand.



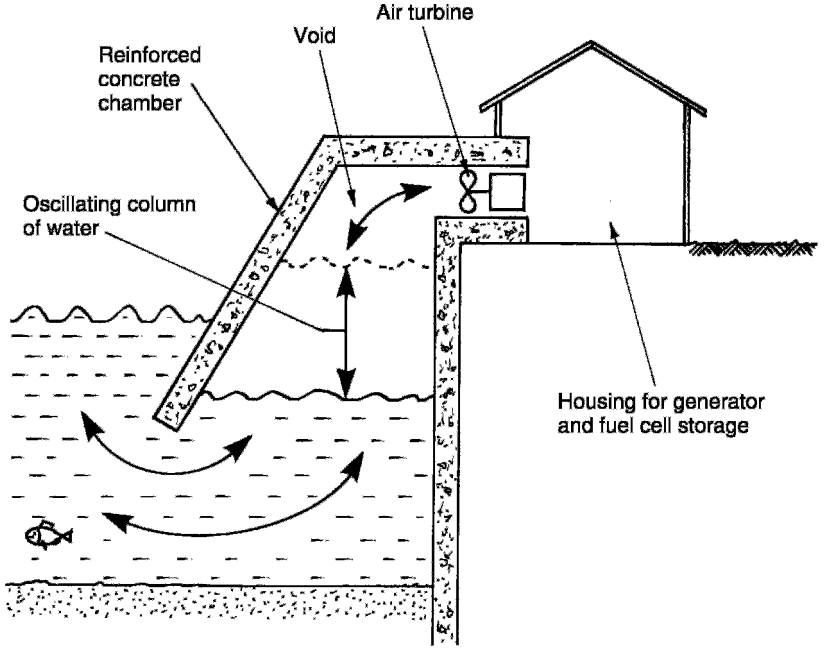
Wind-generated stored electricity

Instead of using the wind-generated electricity directly, it is used to electrolytically decompose water. This means separation of the hydrogen and the oxygen in water into different storage vessels. The stored hydrogen and oxygen are supplied to a fuel cell or battery in regulated amounts to produce a direct current. As the two gases combine they give water, which is returned to the electrolysis cell for reprocessing. Direct current is transformed to alternating current for compatibility with electricity distribution power lines.

The energy potential in differing water levels has been exploited for centuries through water mills and subsequently hydro-electric power. Another application is to build tidal barrages across major estuaries such as the Severn or Mersey. As the tide rises the water would be impounded, to be released back as the tide recedes, using the head or water level differential as a power source. This has been used to good effect since the 1960s at La Rance near St Malo in France.

Another application uses a series of floats moored in the sea to generate an electrical potential as each float moves with the waves. Attempts have also been made to use the floats to rotate a crankshaft. There are limitations with this, not least the obstruction it creates in the sea.

Power potential from waves can also be harnessed by using their movement to compress air in shoreline chambers. Air pressure built up by the wave oscillations is used to propel an air turbine/ electricity generator.



Shoreline wave energy station

This is otherwise known as `hot-dry-rock´ technology, a name which gives some indication of the energy source. Heat energy is produced by boring two or more holes into the granite fissures found at depths up to 4·5 miles (7·2 km) below the earth's surface. Cold water pumped down one borehole and into the fissures converts into hot water or steam which is extracted from the other borehole(s). The hot water can then be used directly for heating or it can be reprocessed into steam to drive turbines and electricity generators on the surface.

Enormous quantities of heat are believed to exist in underground rock formations throughout the world. New Zealand and Iceland are well known for having hot volcanic springs and established use of naturally occurring hot water from geysers. In the UK there are a few isolated examples of spas, but the greatest potential lies below the impermeable granite sub-strata in the south-west corner of England. This concentrates in Cornwall and ranges up to Dartmoor and the Scilly Isles. Geological surveys suggest that the heat energy potential here is twice that elsewhere in the UK. Since the 1970s the centre of research has been at Rosemanowes Quarry, near Falmouth. Indications from this and other lesser sites in the locality are that there may be enough geothermal energy in the west country to provide up to 20% of the UK's electricity needs. Exploration by boreholes into aquifers in other parts of the country have met with some success. In Marchwood, Southampton, water at over 70°C has been found at depths of less than 2 km. However, this resource was found to be limited and not cost effective for long-term energy needs (see next page).

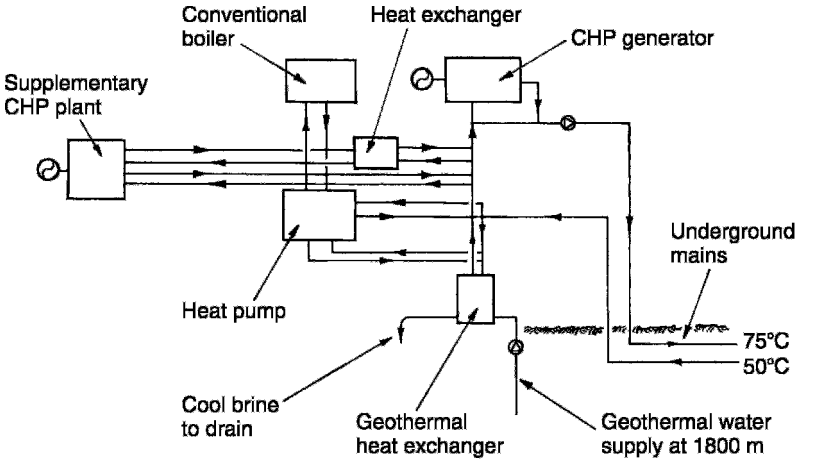
Exploitation of hot water from naturally occurring springs is not new. All over the world there are examples of spas which are known to have been enjoyed since Roman times. More recently in the early 1900s, a natural source of steam was used to generate electricity in Italy. Now it is very much a political and economic decision as to whether it is cost effective to expend millions of pounds exploiting this possibly limited source of heat energy.

Location – during the 1970s and early 1980s, site boreholes were sunk at the Marchwood power station site on Southampton Water and in Southampton centre.

Results – the second borehole near the city shopping centre provided greatest potential, with a water temperature of 76°C at 1800 metres.

Initial outcome – the Department of Energy considered the resource of limited economic value to make a significant contribution nationally.

Later outcome – Southampton City Council took the initiative to form a partnership with Utilicom, a French-owned energy management company to develop a local district heating scheme. Utilicom's parent companies, IDEX and STREC had considerable experience in operating geothermal district heating systems around Paris. In 1986 Utilicom and Southampton City Council formed the Southampton Geothermal Heating Company (SGHC).



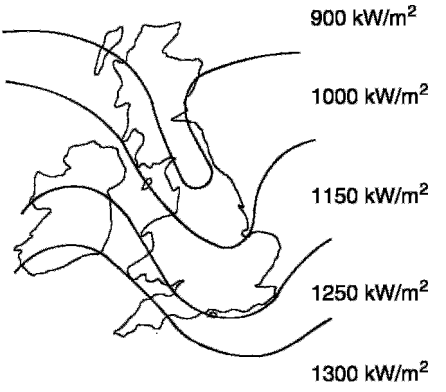
Schematic combined geothermal, CHP and conventional boiler district heating system

Energy use – the geothermal resource provides about 20%, with fuel oil and natural gas approximately 10% and 70%, respectively. A chilled water facility is also provided by the heat pump.

Clients – mainly corporations and commercial premises, although some housing estates and apartment blocks are included.

Commendation – received The Queen's Award for Enterprise: Sustainable Development 2001.

The potential of solar energy as an alternative fuel is underrated in the UK. It is generally perceived as dependent solely on hot sunny weather to be effective. In fact it can be successfully used on cloudy days, as it is the solar radiation which is effective. The average amount of solar radiation falling on a south facing inclined roof is shown to vary between about 900 and 1300 kW/m^2 per year depending on the location in the UK.



Solar radiation averaged over a year
for a 30° pitched roof facing south

The reluctance to accept solar panels in this country is understandable. The capital outlay is quite high and even though it is possible to achieve up to 40% of the average household's hot water requirements from solar energy, the payback period may be in excess of 10 years. It could also be argued that the panels are visually unattractive. The typical installation is shown on page 64. It has a flat plate 'black radiator' solar panel to absorb solar energy in water, which is transferred for storage in an insulated cylinder. From here it supplements hot water from a conventional boiler source. This application is also suitable for heating swimming pools.

An improvement uses collectors inside clear glass vacuum cylinders. These 'evacuated tube collectors' are capable of absorbing more heat at low levels of light. Other types of solar panel which can be used to power batteries or fuel cells include the photovoltaic system. This uses expensive crystalline silicon as a power generator. A less expensive alternative is amorphous silicon. Although less efficient, it is still capable of providing a trickle feed to batteries.

Biomass or Biofuel

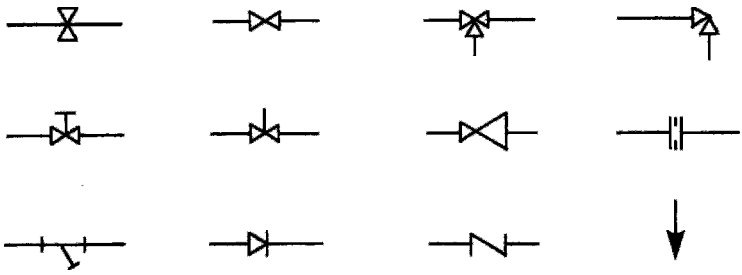
Biomass is current terminology for the combustion of traditional fuels such as wood, straw and cow dung. The difference is that today we have the facility to process and clean the waste products. Gas scrubbers and electrostatic precipitators can be installed in the flues to minimise atmospheric pollution. Intensive farming methods produce large quantities of potentially harmful residues, including straw and chicken droppings. The latter combines with wood shavings and straw from the coops. Instead of burning these as waste, they can be reprocessed. A pioneer scheme at Eye in Suffolk burns the waste in a 10 MW steam turbine electricity generator and sells the ash as an environmentally friendly fertiliser. This has the additional benefits of:

- Eliminating the traditional unregulated burning of farm waste which contaminates the atmosphere with carbon dioxide.
- Destroying the harmful nitrates which could otherwise be released into the soil.
- Destroying the potential for methane generation from decomposition. When this is released into the atmosphere it is far more active than carbon dioxide as a greenhouse gas.

Farm wastes can also be used to produce methane gas for commercial uses. The waste is processed in a controlled environment in large tanks called digesters. The gas is siphoned off and used for fuel, whilst the remains are bagged for fertiliser.

The potential for forest farming wood as a fuel for power generation is also gaining interest. Trees naturally clean the atmosphere by absorbing carbon dioxide. However, when they die, they rot, releasing as much carbon dioxide as absorbed during growth and a significant amount of methane. By controlled burning the carbon dioxide is emitted, but the gains are destruction of the methane and an economic, sustainable fuel supply.

16 APPENDICES



GLOSSARY OF COMMON ABBREVIATIONS

GRAPHICAL SYMBOLS FOR PIPEWORK

IDENTIFICATION OF PIPEWORK

GRAPHICAL SYMBOLS FOR ELECTRICAL INSTALLATION WORK

METRIC UNITS

WATER PRESSURE AND HEAD

CONVERSION OF COMMON IMPERIAL UNITS TO METRIC

BBA – British Board of Agrément. The function of the BBA is to assess, test and establish the quality of new products and innovations not represented by existing British (BSI) or European (CEN) Standards.

BRE – Building Research Establishment. Critically examines products and materials applicable to construction and issues certificates of conformity. Publishes research digests, good practice guides and information papers.

BS – British Standard. Publications issued by the British Standards Institution as support documents and recommendations for minimum practice and product manufacturing standards. Materials and components which comply are kitemarked:



BS EN – A British Standard which is harmonised with the European Standards body, CEN.

CE – Communauté Européenne (European Community). This is a product mark which indicates presumption of conformity with the minimum legal requirements of the Construction Product Regulations 1991. Compliance is manufacture to a British Standard, a harmonised European Standard or a European Technical Approval (ETA).

CEN – Comité Européen de Normalisation. European standardisation body recognised by the European Commission (EC) for harmonising standards of product manufacturers in support of the CPD. Membership of CEN is composed of the standardisation bodies of the participating members of the European Union (EU) and the European Free Trade Association (EFTA). The standardisation body representing the UK is the BSI.

CIRIA – Construction Industry Research and Information Association. An independent research organisation which addresses all key aspects of construction business practice. Its operating principles are on a `not-for-profit´ basis for the benefit of industry and public good.

CPD – Construction Products Directive. Determines that construction products satisfy all or some of (depending on the application) the following essential requirements:

- Mechanical resistance and stability
- Hygiene, health and the environment
- Protection against noise
- Safety in case of fire
- Safety in use
- Energy economy and heat retention

EC – European Commission. The executive organisation of the European Union (EU).

EEA – European Economic Area. Includes the member states of the European Union and 3 of the 4 states of the European Free Trade Association (EFTA): Iceland, Norway and Liechtenstein (Switzerland excluded).

EOTA – European Organisation for Technical Approvals. Operates over the same area as CEN, complementing the work of this body by producing guidelines for new and innovative products.

ETA – European Technical Approval. A technical assessment of products which indicate suitability and fitness for use for the CPD. Authorised bodies working with ETA include the BBA and WIMLAS Ltd (now part of BRE Certification). These bodies also produce technical specifications against which product compliance can be measured for approval.

EU – European Union. A unification of states. Before 2004 comprising 15 countries: Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxemburg, Netherlands, Portugal, Spain, Sweden and the United Kingdom. Thereafter, a further 10: Cyprus, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Malta, Poland, Slovakia and Slovenia.

ISO – International Organisation for Standardisation. This authority issues standards which are appropriate throughout the world. Products are identified with a number following the prefix ISO. Some of these may be adopted by the CPD, e.g. BS EN ISO 6340: Water quality and BS EN ISO 10960: Rubber and plastic hoses.

UKAS – United Kingdom Accreditation Service. An independent certification body that may be used by manufacturers to test and assess the suitability of their material products. UKAS issue certificates to show that materials conform to the criteria required of a recognised document, appropriate for the intended product use and application.

WRC – Water Research Council. A specialist testing agency with its own established brand of approval.

Appendix 2 – Abbreviations for Pipework

Design and installation drawings would be cluttered with writing, if there were not a simple format for representing pipes, fittings and accessories with abbreviations or symbols. The British and European Standards authorities have produced several documents recommending specific notations and symbols for all types of pipework installations, e.g. BS 1553-1 and 2 (see Appendix 5). Nevertheless, many offices prefer to use their own established procedures and variations from the standards. The following indicate some of the established alphabetical representations that may be used on engineering services drawings.

Service	Abbreviation
Boiler feed water	BFW
Brine	B
Chilled water	CHW
Cold water main	MWS
Cold water down service	CWS
Cold water drinking	DWS
Cold water flushing	FWS
Cold water pressurised	PWS
Treated water	TW
Waste water	WW
Condensate	C
Compressed air	CA
Cooling water	CLW
Fire service extinguisher	FE
Fire service hydrant	FH
Fuel	F
Liquefied petroleum gas	LPG
Nitrous oxide gas	N_2O
Oxygen	O_2
Refrigerant gas	R_O
Low pressure hot water heating	LPHW
Medium pressure hot water heating	MPHW
High pressure hot water heating	HPHW
Hot water (domestic)	HWS
Steam	S
Vacuum	V

Component	Abbreviation
Cold feed	CF
Cold water storage cistern	CWSC
Drain or draw off	DO
Expansion vessel	ExVl
Feed and expansion	F & E
Hot water storage cylinder	HWSC
Open vent	OV
Strainer	S
Tundish	T
Warning pipe/overflow	WP
Control valves –	
Air release	ARV
Air	AV
Anti-vacuum	AVV
Automatic air	AAV
Check	CV
Double check	DCV
Drain tap	DT
Expansion	EV
Float	FV
Gate	GV
Lockshield	LSV
Non-return	NRV
Plug cock	PC
Pressure reducing valve	PRV
Servicing	SgV
Stop cock or valve	SC or SV
Temperature and pressure relief	TPRV
Thermostatic radiator	TRV
Wheel valve	WV
Pipework positions and direction –	
Flow	F
Return	R
From above	FA
To above	TA
From below	FB
To below	TB
High level	HL
Low level	LL

Appendix 4 – Abbreviations Used for Drainage Systems

Component and service	Abbreviation
Drains –	
Foul water	FWD
Surface water	SWD
Sewers –	
Foul water	FWS
Surface water	SWS
Effluents –	
Foul water	FW
Radio active water	RAW
Rain water	RW
Surface water	SW
Means of access, etc. –	
Access cover	A/C
Back drop	BD
Cleaning or rodding eye	CE or RE
Fresh air inlet	FAI
Half round channel	HRC
Invert	INV
Manhole	MH
Rainwater head	RWH
Rainwater shoe	RWS
Shallow access chamber	SAC
Gullies –	
Access	AG
Back inlet	BIG
Grease trap	GT
Road	RG
Sealed	SG
Yard	YG

Component and service	Abbreviation
Pipes –	
Discharge pipe	DP
Rainwater pipe	RWP
Soil and ventilating pipe or stack	SVP or SVS
Vent pipe or stack	VP or VS
Waste pipe	WP
Sanitary fittings –	
Access cap	ac
Air admittance valve	aav
Bath	b
Bidet	bt
Drinking fountain	df
Flushing cistern	fc
Shower	sh
Sink	s
Urinal	u
Wash basin	wb
Water closet	wc
Materials –	
Acrylonitrile butadiene styrene	ABS
Cast iron	CI
Copper	Cu
Heavy duty polypropylene	HDPP
High density polyethylene	HDPE
Medium density polyethylene	MDPE
Modified unplasticised polyvinyl chloride	MUPVC
Polypropylene	PP
Unplasticised polyvinyl chloride	uPVC or PVCu

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Further references for specific applications –

BS 1553: Specification for graphical symbols for general engineering.

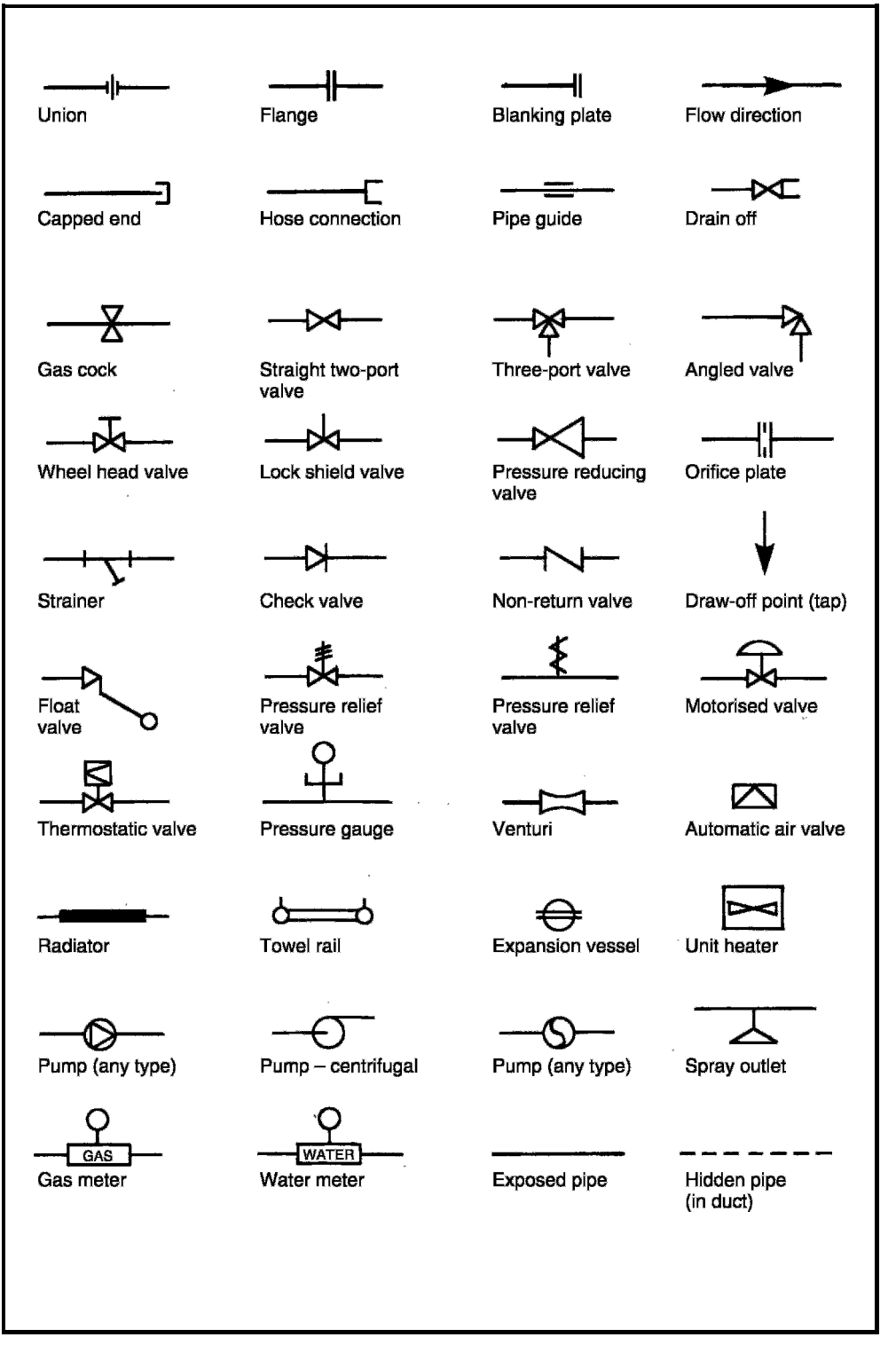
Part 1: Piping systems and plant.

Part 2: Graphical symbols for generating plant.

BS 1635: Recommendations for graphic symbols and abbreviations for fire protection drawings.

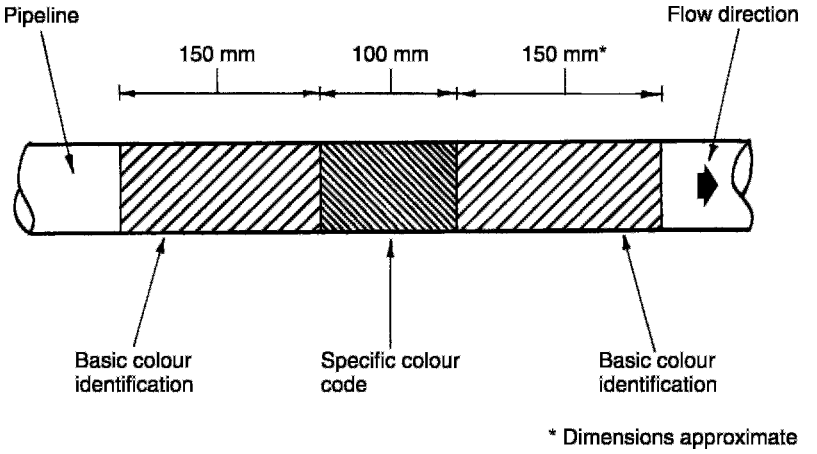
BS EN ISO 6708 & BS 308: Technical drawings. Simplified representation of pipelines.

BS EN 1861: Refrigerating systems and heat pumps. System flow diagrams and piping and instrument diagrams. Layout and symbols.


Union
Flange
Blanking plate
Flow direction
Capped end
Hose connection
Pipe guide
Drain off
Gas cock
Straight two-port valve
Three-port valve
Angled valve
Wheel head valve
Lock shield valve
Pressure reducing valve
Orifice plate
Strainer
Check valve
Non-return valve
Draw-off point (tap)
Float valve
Pressure relief valve
Pressure relief valve
Motorised valve
Thermostatic valve
Pressure gauge
Venturi
Automatic air valve
Radiator
Towel rail
Expansion vessel
Unit heater
Pump (any type)
Pump – centrifugal
Pump (any type)
Spray outlet
GAS
Gas meter
WATER
Water meter
Exposed pipe
Hidden pipe (in duct)

Where a large quantity of piped services are deployed in boiler rooms, process plant service areas, etc., identification of specific services, e.g. compressed air, chilled water, etc., can be very difficult and time consuming. The situation is not helped when installation drawings are lost or may not even have existed. Also, modifications could have occurred since original installation. This is made more difficult where a common pipe material such as galvanised steel is used for a variety of services.

The recommendations of BS 1710 have improved the situation considerably by providing a uniformly acceptable colour coding. This has also been endorsed by the Health & Safety (Safety Signs & Signals) Regulations which require visible markings on all pipework containing or transporting dangerous substances. Direction of flow arrows should also complement coloured markings. Colours can be applied by paint to BS 4800 schedules or with proprietory self-adhesive tape.

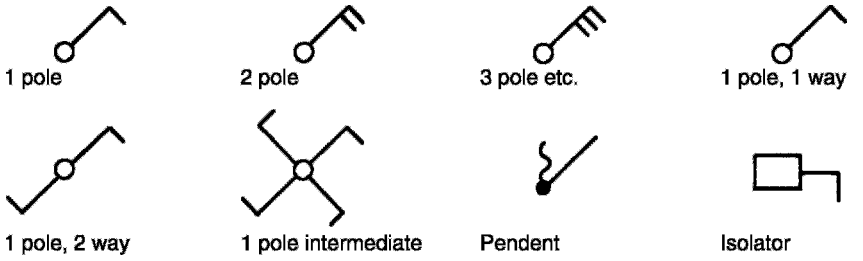


Refs. BS 1710: Specification for identification of pipelines and services.
BS 4800: Schedule of paint colours for building purposes.
Health & Safety (Safety Signs & Signals) Regulations 1996.

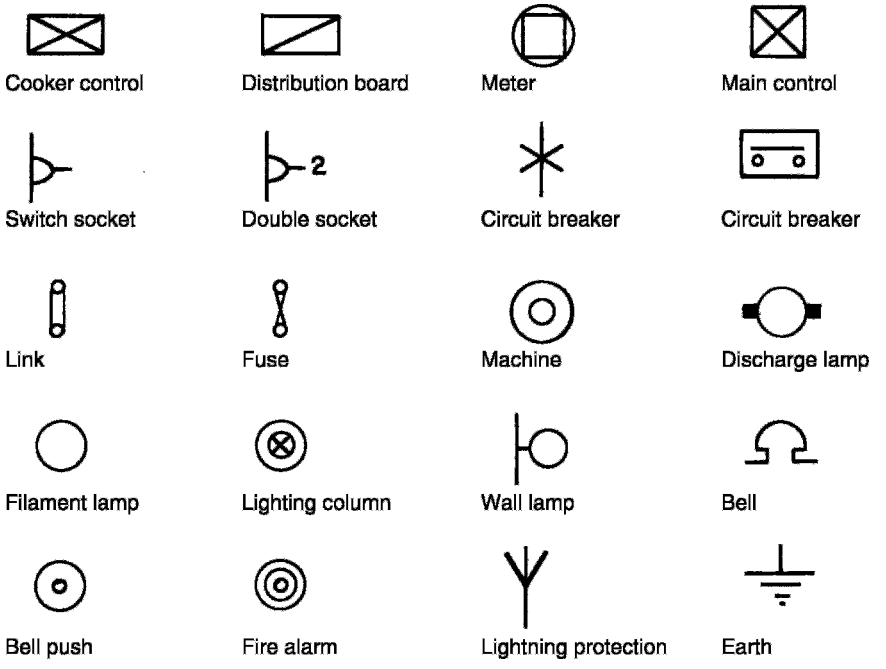
Appendix 7 – Identification of Pipework (2)

Contents	Basic i.d. colour	Specific colour	Basic i.d. colour
Water:			
Drinking	Green	Auxiliary blue	Green
Cooling (primary)	Green	White	Green
Boiler feed	Green	Crimson.White.Crimson	Green
Condensate	Green	Crimson.Emerald green. Crimson	Green
Chilled	Green	White.Emerald green. White	Green
Heating <100°C	Green	Blue.Crimson.Blue	Green
Heating >100°C	Green	Crimson.Blue.Crimson	Green
Cold down service	Green	White.Blue.White	Green
Hot water supply	Green	White.Crimson.White	Green
Hydraulic power	Green	Salmon pink	Green
Untreated water	Green	Green	Green
Fire extinguishing	Green	Red	Green
Oils:			
Diesel fuel	Brown	White	Brown
Furnace fuel	Brown	Brown	Brown
Lubricating	Brown	Emerald green	Brown
Hydraulic power	Brown	Salmon pink	Brown
Transformer	Brown	Crimson	Brown
Refrigeration:			
Refrigerant 12	Yellow ochre	Blue	Yellow ochre
Refrigerant 22	Yellow ochre	Green	Yellow ochre
Refrigerant 502	Yellow ochre	Brown	Yellow ochre
Ammonia	Yellow ochre	Violet	Yellow ochre
Others	Yellow ochre	Emerald green	Yellow ochre
Other pipelines:			
Natural gas	Yellow ochre	Yellow	Yellow ochre
Compressed air	Light blue	Light blue	Light blue
Vacuum	Light blue	White	Light blue
Steam	Silver grey	Silver grey	Silver grey
Drainage	Black	Black	Black
Conduit/ducts	Orange	Orange	Orange
Acids/alkalis	Violet	Violet	Violet

Switches (rows 1 and 2)



Other fittings and accessories



Note: In addition to established office practice, the following standards provide recommendations for drawing representations:
BS EN 61082-2: Preparation of documents used in electrotechnology. Function oriented diagrams.
BS 1553-1: Specification for graphic symbols for general engineering. Piping systems and plant.

Metric measurements have been officially established in the UK since the Council of Ministers of the European Community met in 1971 to commit member countries to an International System of Units (SI). This has been endorsed by the International Organisation for Standardisation (ISO).

Basic or primary units:

Quantity	Unit	Symbol
Length	metre	m
Mass	kilogram	kg
Time	second	s
Electric current	ampere	A
Temperature	Kelvin	K
Luminous intensity	candela	cd

Some commonly used supplementary and derived units:

Quantity	Unit	Symbol
Area	square metre	m^2
Volume	cubic metre	m^3
Velocity	metres per second	m/s
Acceleration	metres per second squared	m/s^2
Frequency	hertz (cycles per second)	Hz
Density	kilogram per cubic metre	kg/m^3
Force	newton	N
Moment of force	newton metre	N m
Pressure	newton per square metre	N/m^2 (pascal – Pa)
Work, energy and heat	joule	J
Power, heat flow rate	watt	W (J/s)
Temperature – customary unit	degree Celsius	°C
Temperature – interval	degree Kelvin	K

Note: degree Celsius and Kelvin have the same temperature interval. Kelvin is absolute temperature with a zero factor equivalent to –273·15°C, i.e. 0°C = 273·15 K.

Further derived units:

Quantity	Unit	Symbol
Density of heat flow	watt per square metre	W/m^2
Thermal conductivity	watt per metre degree	W/m K
Heat transfer (U value)	watt per square metre degree	W/m^2 K
Heat capacity	joule per degree	J/K
Specific heat capacity	joule per kilogram degree	J/kg K
Entropy	joule per degree	J/K
Specific entropy	joule per kilogram degree	J/kg K
Specific energy	joule per kilogram	J/kg

Derived units for electrical applications:

Quantity	Unit	Symbol
Electric charge	coulomb	C (As)
Potential difference	volt	V (W/A)
Electromotive force	volt	V (W/A)
Electric field strength	volt per metre	V/m
Electric resistance	ohm	Ω (V/A)
Electric capacitance	farad	F (As/V)
Magnetic flux	weber	Wb (Vs)
Magnetic field strength	ampere per metre	A/m
Inductance	henry	H (Vs/A)
Luminous flux	lumen	lm
Luminance	candela per square metre	cd/m^2
Illuminance	lux (lumens per square metre)	lx (lm/m^2)

Multiples and submultiples:

Factor	Unit	Name	Symbol
One billion	10^{12}	tera	T
One million million	10^{12}	tera	T
One thousand million	10^{9}	giga	G
One million	10^{6}	mega	M
One thousand	10^{3}	kilo	k
One hundred	10^{2}	hecto	h
Ten	10^{1}	deca	da
One tenth	10^{-1}	deci	d
One hundreth	10^{-2}	centi	c
One thousandth	10^{-3}	milli	m
One millionth	10^{-6}	micro	μ
One thousand millionth	10^{-9}	nano	n
One million millionth	10^{-12}	pico	p
One billionth	10^{-12}	pico	p
One thousand billionth	10^{-15}	femto	f
One trillionth	10^{-18}	atto	a

Common units for general use:

Quantity	Unit	Symbol
Time	minute	min
	hour	h
	day	d
Capacity	litre	l (1 l = 1 dm^3) (1000 l = 1 m^3)
Mass	tonne or kilogram	t (1 t = 1000 kg)
Area	hectare	ha (100 m × 100 m) (10 000 m^2)
Pressure	atmospheric	atm (1 atm = 101·3 kN/m^2)
Pressure	bar	b (1 bar = 100 kN/m^2)

Head (metres)	Pressure kN/m² (kPa)	Pressure mbar or bar
1.00	9.81	98.7 mbar
1.02	0.00	100.00
2.00	19.61	196.13
2.04	20.00	200.00
3.00	29.42	294.19
3.06	30.00	300.00
4.00	39.23	392.26
4.08	40.00	400.00
5.00	49.03	490.33
5.10	50.00	500.00
6.00	58.84	588.39
6.12	60.00	600.00
7.00	68.65	686.46
7.14	70.00	700.00
8.00	78.45	784.53
8.16	80.00	800.00
9.00	88.26	882.59
9.18	90.00	900.00
10.00	98.07	980.66
10.20	100.00	1.00 bar
11.00	107.87	1.08
11.22	110.00	1.10
12.00	117.68	1.18
12.24	120.00	1.20
13.00	127.49	1.27
13.26	130.00	1.30
14.00	137.29	1.37
14.28	140.00	1.40
15.00	147.10	1.47
15.30	150.00	1.50
16.00	156.91	1.57
16.32	160.00	1.60
18.00	176.52	1.77
18.36	180.00	1.80
20.00	196.13	1.96
20.40	200.00	2.00
30.00	294.20	2.94
30.59	300.00	3.00
50.00	490.33	4.90
50.99	500.00	5.00
100.00	980.66	9.81
101.97	1.00 MN/m²	10.00
200.00	1.96	19.61
203.94	2.00	20.00

Appendix 11 – Conversion of Common Imperial Units to Metric (1)

Length	1 mile = 1·609 km 1 yd = 0·914 m 1 ft = 0·305 m (305 mm)
Area	1 sq. mile = 2·589 km^2 or 258·9 ha 1 acre = 4046·86 m^2 or 0·404 ha 1 yd^2 (square yard) = 0·836 m^2 1 ft^2 (square foot) = 0·093 m^2 1 in^2 (square inch) = 645·16 mm^2
Volume	1 yd^3 (cubic yard) = 0·765 m^3 1 ft^3 (cubic foot) = 0·028 m^3 1 in^3 (cubic inch) = 16387 mm^3 (16·387 cm^3)
Capacity	1 gal = 4·546 l 1 qt = 1·137 l 1 pt = 0·568 l
Mass	1 ton = 1·016 tonne (1016 kg) 1 cwt = 50·8 kg 1 lb = 0·453 kg 1 oz = 28·35 g
Mass per unit area	1 lb/ft^2 = 4·882 kg/m^2 1 lb/in^2 = 703 kg/m^2
Mass flow rate	1 lb/s = 0·453 kg/s
Volume flow rate	1 ft^3/s = 0·028 m^3/s 1 gal/s = 4·546 l/s
Pressure	1 lb/in^2 = 6895 N/m^2 (68·95 mb) 1 in (water) = 249 N/m^2 (2·49 mb) 1 in (mercury) = 3386 N/m^2 (33·86 mb)

Energy	1 therm = 105·5 MJ 1 kWh = 3·6 MJ 1 Btu (British thermal unit) = 1·055 kJ
Energy flow	1 Btu/h = 0·293 W (J/s) (see note below)
Thermal conductance	1 Btu/ft^{2}h °F = 5·678 W/m^2 K (`U' values)
Thermal conductivity	1 Btu ft/ft^{2}h °F = 1·730 W/m K
Illumination	1 lm/ft^2 = 10·764 lx (lm/m^2) 1 foot candle = 10·764 lx
Luminance	1 cd/ft^2 = 10·764 cd/m^2 1 cd/in^2 = 1550 cd/m^2
Temperature	32°F = 0°C 212°F = 100°C
Temperature conversion	Fahrenheit to Celsius (°F – 32) × 5/9 e.g. 61°F to °C (61 – 32) × 5/9 = 16·1°C
Temperature conversion	Fahrenheit to Kelvin (°F + 459·67) × 5/9 e.g. 61°F to K (61 + 459·67) × 5/9 = 289·26 K, i.e. 289·26 – 273·15 = 16·1°C

Note regarding energy flow:
Useful for converting boiler ratings in Btu/h to kW,
e.g. a boiler rated at 65 000 Btu/h equates to:
65 000 × 0·293 = 19 045 W, i.e. approx. 19 kW.

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